Casting no shadow: Overlapping Soilscapes of European – Indigenous Interaction in Northern Sweden

Heather Fiona Green

Thesis submitted for the degree of
Doctor of Philosophy
Biological and Environmental Sciences,
University of Stirling

2012

Statement of originality

I hereby confirm that this is an original study conducted independently by the undersigned and that the work contained therein has not been submitted for any other degree. All research material has been duly acknowledged and cited.

Signature of candidate:

Date:

Abstract

The Sámi's past activities have been documented historically from a European perspective, and more recently from an anthropological viewpoint, giving a generalised observation of the Sámi, during the study period of AD200-AD1800, as semi-nomadic hunter gatherers, with several theories suggesting that interaction with Europeans, through trade, led to the adoption of European activities by certain groups of the Sámi (Eiermann, 1923; Paine, 1957; Manker and Vorren, 1962; Bratrein, 1981; Mathiesen *et al*, 1981; Meriot, 1984). However, there is almost no information on the impact the Sámi had on the landscape, either before or after any adoption of European activities, and none investigating what cultural footprint or indicators would remain from Sámi or European occupation and/or activity within the typically podzolic soils of Northern Sweden. Consequently the thesis aims to contribute to the gap in knowledge through the formation of a podzol model identifying the links between anthropogenic activity and the alteration of podzol soils, and through the creation of soils based models which identify the cultural indicators associated with both Sámi and European activity; formed from the identification of cultural indicators retained within known Sámi and European sites. The methods used to obtain the information needed to achieve this were the pH and magnetic susceptibility from bulk soil samples and micromorphological and chemical analysis of thin section slides through the use of standard microscopy and X-ray fluorescence from a scanning electron microscope.

The analysis revealed that the Sámi had an extremely low impact on the landscape, leaving hard to detect cultural indicators related to reindeer herding in the form of reindeer faecal material with corresponding phosphorous peaks in the thin section slides. The European footprint however, was markedly different and very visible even within the acidic soil environment. The European indicators were cultivation based and included phosphorous and aluminium peaks as well as a deepened, highly homogenised plaggen style anthropogenic topsoil rich in 'added' materials. An abandoned European site which visibly and chemically shows the formation of a secondary albic horizon within the anthropogenic topsoil also provides an insight into the delicate balance of cultivated soil in northern Sweden, whilst reinforcing the outputs identified in the podzol model. Due to the almost invisible Sámi footprint on the landscape, areas of overlap were impossible to identify however, there was no evidence of the adoption of European cultivation activities at any of the Sámi sites investigated. The only known area of interaction between the two cultures was an official market place which had been a Sámi winter settlement prior to its use as a market site. This site showed none of the reindeer based Sámi indicators or the cultivation based European indicators, but did contain pottery fragments which could be linked to trade or occupation. Overall, the thesis reinforces the low impact expected of the semi-nomadic Sámi and sheds light on the underlying podzolic processes influencing the anthropogenically modified soils of Northern Sweden. The podzol model is reinforced by several findings throughout the thesis and the soils based cultural indicator models for both Sámi and European activity have been successfully tested against independent entomological and palynological data and therefore provide reliable reference material for future studies.

Acknowledgments

Firstly I'd like to thank the elusive Ian Simpson, firstly for having enough faith in me to take me on, but also for his helpful advice when captured. Staying within Stirling University I'd also like to thank George MacLeod for teaching me how to manufacture the thin section slides and for producing the bulk of my samples, to Kirsty Golding and Bill Jamieson for their advice with the Illustrator software, to Helen Ewan for her patience and good humour with the lab equipment, to Kate Howie for her statistical advice, to Jen Brown for allowing me to help her with her fieldwork in Iceland for my undergraduate dissertation, as that is what started all of this off, and to Val Dufeu for proof reading through my earlier chapters, your advice was most appreciated. I'd also like to thank Eileen Tisdall and Charley French for their valuable feedback during the Viva.

I'd like to thank all those at the Skogsmusset, Lycksele, for the invaluable advice and leads throughout my fieldwork there, to the landowners of the sites for letting me dig up their land (especially the elderly neighbour who brightened up a miserable day by using Charades to ask if I was burying a dog), and to everyone that I've met at various conferences and workshops for treating me as an equal and allowing me to bounce ideas off of them, particularly Richard Macphail who was always patient regardless of the number, and quality, of questions asked of him.

To the Leverhulme trust for funding the PhD and to everyone else involved in the project for their help in organising, and during, the fieldwork, particularly Eva Panagiotakopulu who turned fieldwork into an adventure, and to Sara and Ilse for sharing some of their results so that I could test my models.

And as always the best has been saved till last, I'd like to thank my family for the continued support throughout the years, particularly my parents, brothers and late grandparents, your faith in me is what carried me through the darker days, and Robbie, whom I must credit for the title of the thesis, your unyielding attempts to get me to treat my PhD as a military operation has caused no end of arguments, but knowing that you cared enough to keep trying means the world to me.

Thank you.

Contents

List of figures

List of tables

Chapter 1: Introduction

1 Introduction

1.1 Thesis objectives

The objectives of the thesis are listed below and hinge on establishing which cultural indicators are retained in the soils of northern Sweden so that, once identified, they can be used to establish what land management techniques were employed by both the indigenous Sámi, and the settling European populations, so that a soils based model of occupation can be constructed for each. The principal aim of the thesis is centred on this concept of interaction between the two cultures leading to the adoption of European style practises by the traditionally semi-nomadic Sámi. Consequently the soils based models for each culture will be used to identify if either culture adapted their traditional cultural practises as a result of interaction. Broken down these objectives are:

1. To identify and review key information relating to the retention of cultural indicators in podzolic soils, the 'typical' activities of both the Sámi and European cultures between AD1200 – AD1800, and the relationship the cultures had with one another

2. To establish what cultural indicators are retained in Scandinavian soils, both podzolic and anthropogenically amended, using field analysis, soil micromorphology and chemical analysis

3. To establish what cultural indicators are associated with both Sámi and European occupation through the production of a soils based model

4. To use the knowledge gained from the previous aims to look for evidence of interaction between the cultures, and if present, to identify what these changes were and the impact they had on the soilscape

1.2 Thesis structure

Chapter 1 introduces the thesis topic and the specific aims before going into a literature search and review. The literature search and review will tackle the use of soil as a cultural record, traditional Sámi and European culture and interaction between the two cultures. The methodology, chapter 2, goes through the methods used and the reasons why from the planning of the fieldwork through to the laboratory analysis.

Chapter 3, the soils chapter, is crucial in understanding the background podzolic processes affecting the cultural indictors. A background on podzol formation is given prior to the development of a podzol model, formed through a literature search on anthropogenic influences on and from podzol soils. This is then used to discuss the cultural indicators anticipated at the Sámi and European sites.

Chapters 4 and 5, The Sámi landscape and European landscape respectively, goes through the site history and analysis (field, chronological, micromorphological and chemical) for each site before comparing some of the key features identified. All of the information is then used to form a soil model giving the cultural indicators associated with occupation and/or activity. Lastly the discussion chapter, chapter 6, compares and contrasts the Sámi and European results for all of the analysis carried out in order to identify any areas of overlap and/or interaction and finalise the soils based models for each culture. The models are then tested against independent data to check their accuracy prior to the final conclusions being drawn; the final conclusions will discuss if and how each of the thesis aims have been met, before introducing any areas of future study which have been identified from this work.

1.3 Soils section

1.3.1 Introduction

An expanse of research has been dedicated towards the Sámi, the indigenous population of Scandinavia, which has centred upon anthropological study; such as Skandfer's (1999) work on the Sámi's local knowledge of different sites. Although the 'typical' Sámi culture of AD1200-AD1800 have been described as semi-nomadic hunter gatherers, there are also several theories suggesting that interaction with the settling Europeans led to the adoption of a more Europeanised attitude by the Sámi (Paine, 1957; Manker and Vorren, 1962; Bratrein, 1981; Mathiesen *et al*, 1981; Meriot, 1984); a full literature search has been conducted for the 'typical' Sámi and European activities in addition to a further sub-chapter on possible interaction later in this chapter. The interaction between the two cultures has been well documented and theorised, sometimes with contradictive views. However little literature exists on the impact either culture had on the landscape after, and in the Sámi's case also before, any theorised adaption of daily activities by either culture. In order to ascertain what adaptions, if any, were made by either/both culture as a result of interaction a footprint of each culture prior to interaction must be obtained. In order to do this the base soil type of the area, podzolic, must be addressed.

Previous studies of soils and sediments that have investigated anthropogenic activity within podzol soils, such as the work done by Kristiansen (2000), have concentrated on establishing if human influence can change a podzols properties. However they have not looked at how podzol soils retain cultural information. As a result, and in order to establish a footprint for each culture, the historic cultural indicators retained, and if and how these are modified as a result of being retained within a podzol soil, must be identified. The information gained from this will then be used to establish a cultural record of podzolic and anthropogenically modified Swedish soils.

This study will therefore address and add to two separate areas of knowledge. Firstly, is the knowledge gained with reference to cultural indicators within podzolic soils, i.e. which are retained, which are modified and which are lost, which can be applied internationally. Secondly is the cultural knowledge gained regarding the indigenous Sámi population and the settling Europeans of Northern Sweden. The identification of a Sámi footprint within the soil will provide evidence of their occupation, with a soils based model allowing for future identification of Sámi activity areas which can be applied across Scandinavia. The equivalent soils based model for the European settlements will provide additional information to the existing knowledge in the form of how their impact is recorded within, and exacerbated or improved by, podzol based soils.

1.3.2 **Geoarchaeology & soil as a cultural record**

Geo-archaeology is a combination of geomorphology and archaeology and is aimed at recognising how both natural and human induced processes can alter the landscape (French, 2003). Any human alteration of a landscape is retained in its soils, paleosols and related geologic sediments (Rapp *et al*, 1998), therefore soils based analysis, especially when literary evidence of land use and change are limited, is an essential element in establishing what happened, when, and therefore acting as a cultural record. This is important as understanding past landscape activities can explain how the present landscape has come to be (Simpson *et al*, 1998).

In the past soil analysis as a cultural record was viewed as a speculative and unreliable discipline as there were too many variables in terms of soil structure and pedo-feature development, as well as the effects of human activities such as tilling, and climate change related activities such as ground heaves from frost, that can skew the samples

(French, 2003). However like the notable increases in precision with pollen analysis (Tipping, 1998), soil analysis is now a key feature in identifying the cultural record.

It is already known that human activity can alter a landscape, and in certain areas and contexts it is known what activities can alter it and even how much by. These ‘known’ alterations however are location specific and vary between geographical locations due to differing climates, soil types and cultural approaches to land-use (Goudie, 1990).

1.3.3 Cultural indicators retained in anthropogenic soils

Historical cultural indicators retained within the soil can be used to establish the past land management regimes of those who occupied the site, as well as to further, where possible, our understanding of their day to day life beyond land use. Typical cultural indicators retained within the soil, which are associated with cultivation include, but are not limited to, the visible presence of ard or ploughmarks within the anthropogenic horizon, as well as the inclusion of ‘added’ materials such as bones, both marine and terrestrial, manure, organic materials, ash, charcoal and other charred materials (Simpson *et al*, 1998; Simpson *et al*, 2000); or evidence of added materials since decomposed such as egg shells from intestinal parasites which indicate manure (Geel *et al*, 2003).

Depending upon the cultural indicators found and what additional information can be derived from further analysis of the soil i.e. chemical analysis, a picture of past land use can be drawn up, which when coupled with chronological data from radiocarbon dated material, can be used to create a sequential view of past land use including any changes in land management regimes.

The cultural indicators that are associated with European activity and cultivation practises and which will be used in this study can be split into visible indicators such as ploughmarks (Bryant & Davidson, 1996) to chemical indicators such as raised phosphorus levels (Bryant & Davidson, 1996; Simpson, 1997; Dercon *et al*, 2005). Structural changes to the soil, such as a change in the microstructure from platy to spongy micro-structure (Bryant & Davidson, 1996; Simpson et al, 2000), and the inclusion of anthropogenic materials such as charcoal, coprolites, phytoliths, ash and bone (Bryant & Davidson, 1996; Simpson, 1997; Simpson *et al*, 2000), and disturbance related features such as pore infillings in the thin section slides can also be indicators of anthropogenic activity (Bryant & Davidson, 1996). Animal husbandry can be indicated by changes to the soil such as the inclusion of faecal material, and any phytoliths and/or coprolites contained within this, through to chemical evidence such as increased phosphorous levels within the soil (Courty *et al*, 1991; Matthews *et al*, 1997); all indicators mentioned are listed in table 1.1.

1.3.4 **Cultural indicators retained in podzol soils**

Not all soils retain cultural indicators equally, podzol soils are very acidic in nature with pH values below 4.5 (Czimczik *et al*, 2005), which will affect how they retain these indicators. There is virtually no reading material available on traditional cultural indicators in podzol soils, which may either be due to the acidic nature of the soil destroying any indicators, or it could be related to the characteristic infertility of the podzol soils whereby there has been no anthropogenic activity within the soil and therefore no cultural indicators to record.

Several of the more common indicators associated with anthropogenic activity, such as terrestrial and marine bone, phytoliths, diatoms and calcareous ashes (Miller, C. *pers. comm*), will have been destroyed by the acidic environment (Garland & Janaway, 1989). Typical indicators which should survive the acidic conditions are limited and could include visible indicators, such as plough or ard marks, and inclusions of charcoal within the soil (Miller, C. *pers. comm*). However, chemical and structural changes within the soil such as changes to the humic state, pH, texture, chemical composition and availability of water stable aggregates in the soil should be unchanged and could be key indicators of anthropogenic influence (Snakin & Prisyazhnaya, 1997; Mineev *et al*, 1999; Kristiansen, 2000; Kanev *et al*, 2005; Kanev *et al*, 2005; Litvinovich & Pavlova, 2002; Kuznetsova *et al*, 2009); table 1.2 details anticipated cultural indicators expected to be present in podzol soils.

Table 1.1: Table detailing cultural indicators associated with Sámi and European occupation

	Visual		Micromorphological										Chemical	
	Ploughmarks	Disturbed horizons	Bone*	Charcoal	Burnt material	Ash	Type 113 fungal spores	Mite excrement	Coprolites	Phytoliths	Coatings & infillings	Microstructure	Increased P	Magnetic susceptibility
European	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Sámi	×	?	?	✔	?	✔	?	?	?	?	?	✔	?	✔

Key:

✔	Yes
×	No
?	Unknown

**Either marine or terrestrial bone*

Table 1.2: Revised table detailing anticipated cultural indicators retained within podzol based soils, which are associated with Sámi and European occupation

	Visual		Micromorphological										Chemical	
	Ploughmarks	Disturbed horizons	Bone*	Charcoal	Burnt material	Ash	Type 113 fungal spores	Mite excrement	Coprolites	Phytoliths	Coatings & infillings	Microstructure	Increased P	Magnetic susceptibility
European	✔	✔	×	✔	✔	×	✔	✔	×	×	?	✔	✔	✔
Sámi	×	?	×	✔	?	×	?	?	×	×	?	✔	?	✔

1.3.5 Cultural indicators associated with study sites

The sites for this study include both European and Sámi sites. The European sites all have anthropogenic topsoils, however these have formed either from the native podsol or on top of it. Although anthropogenic topsoils typically have a pH of 7+ (FAO, 2006) they can also be acidic, for example the Esch topsoil's in Germany, which have a pH range of 3.5 – 5 (Blume and Leinweber, 2004). If the inherent acidity of the original or underlying podzol influences what could already be an acidic anthropogenic topsoil it may affect any retained cultural indicators within that horizon. Table 1.1 details some of the cultural indicators which are associated with Sámi and European occupation and table 1.2 details the cultural indicators associated with Sámi and European occupation which could still be retained within acidic soils.

The range of possible cultural indicators associated with Sámi occupation is markedly different to those already discussed for European cultivated sites as Europeans are associated with a strong agricultural signal; see table 1.1. Traditional Sámi land use will be fully explored in the following sub-chapter however for clarity in this section it must be noted that the Sámi were traditionally a hunter gatherer culture with sub-groups involved in, amongst other activities, reindeer herding (Eiremann, 1923; Aronsson, 1991; Mulk, 1991; Wheelersberg, 1991). Possible cultural indicators associated with a low impact lifestyle such as the Sámi's is much more limited than that of European cultivation and much more likely to be centred on 'home' activities such as cooking and food preparation; see table 1.1 for a summary of indicators associated with Sámi occupation. There is however a possibility of cultural indicators in the form of compaction and other indicators of animal husbandry on reindeer grazing trails, pen sites and milking sites (Aronsson, 1991), and chemical signatures in the form of elevated phosphorus levels from the reindeer manure (Courty *et al*, 1991; Matthews *et al*, 1997; Simpson *et al*, 2000) which have been linked to pastoral settlements in Kenya (Shahack-Gross *et al*, 2002; Shahack-Gross *et al*, 2008).

There is also the possibility that infillings and coatings related to anthropogenic activity at both Sámi and European sites may be further altered, or even hidden, by the natural illuviation/eluviation processes associated with the podzolisation process. Phosphorus availability decreases with acidity due to the fixation of phosphorous (P) by Aluminium between a pH range of 4-6 and by Iron at pH values below 3 (Hinsinger, 2001). Although this affects the fertility of the soil it should not affect its use as a cultural indicator as total P will be measured and used as an indicator rather than available P.

The cultural indicators associated with European activity were discussed in section 1.2.3, with anthropogenically created or altered soils being classed as a reliable sign of European farming activity. Table 1.1, associated cultural indicators, and table 1.2, anticipated cultural indicators, list the cultural indictors discussed for both Sámi and European occupation. The key indicates that there are expected indicators, i.e. yes or no, but there also question marks where there is any uncertainty. Table 1.1 highlights which cultural indicators should be present at European and Sámi sites, but as some are expected to have been affected by the acidic conditions of the soil table 1.2 has been created to show those still likely to present at the study sites.

1.4 Traditional Sámi culture

The Sámi are traditionally stereotyped as reindeer herders or hunters and although reindeer herding is still a common occupation in the culture today it had not always been so (Urbańczyk, 1992). Before the large scale domestication of reindeer, thought to have occurred sometime after the first record of tame reindeer in AD800 (Aronsson, 1991)**,** the characteristic lifestyle was of semi-nomadic hunter gatherers (Meriot, 1984); however other sub-cultures also existed.

The first reference to the Sámi people was in the time of Tacitus around AD98 who described them as savages (Meriot, 1984). Consistent references to the Sámi were then recorded in the Norwegian and Icelandic Saga’s (Mundal, 2000). Depending upon the author, source and time of publication, different views of the Sámi have been expressed. Historically, the two main views are either the humanitarian view, where the Sámi are described as excellent hunters with a wealth of spiritual and medical knowledge (Kvist, 1992), or there is the more bigoted 'occupier' type view, similar to how the settlers viewed the native Red-Indians in North America (Oliver, 2010), as expressed by Tacitus who described the Sámi as savages who slept on the ground, wore animal skins, did not have horses and used basic materials such as bone for hunting rather than modern iron (Meriot 1984).

It was recorded in the great Saga's of Norway and Iceland that the Sámi way of life was well known to the Norse, but mysterious to them (Mundal, 2000). There were culturally different groups within the Sámi (Urbańczyk, 1992) but for the purposes of this study only generalised views of the semi-nomadic mountain Sámi and the more permanently settled sea Sámi will be discussed. The forest Sámi are seen as the more culturally traditional group who were semi-nomadic, relied on fishing, hunting and gathering of goods (Johansen and Vorren, 1986), and followed the reindeers migratory patterns both when hunting reindeer, and later when reindeer were domesticated and herded (Mulk, 1991). This migratory pattern took them to the coast during the summer months and back into the mountains during the winter (Mulk, 1991) and was beneficial to them as it allowed the Sámi to exploit all available natural resources, which were limited due to the harsh environment (Meriot, 1984; Mulk, 1991; Urbańczyk, 1992). During the winter period, family groups, known as 'siida' communities, would come together and reside at the same winter camp (Mulk, 1991), which consisted of wood and turf constructed cots (Aronsson, 1991; Andersen, 2011). Within the camp, everyone would be assigned a different task including people to look after the camp itself, berry collectors, people to go with and look after the reindeer once herding had been established and hunting groups, typically of 8-12 'men' (Mulk, 1991). Skis were used by the Sámi during the winter period both for transport and for hunting (Meriot, 1984; Urbańczyk, 1992). The skis used are similar to modern cross country or 'Nordic' skis and had reindeer fur attached to the bottom of the left ski and a groove in the right to prevent the skier from slipping backwards when going uphill (Gjerset, 1915; Meriot, 1984; Sturluson, 2000); according to Saga references the Sámi skiers could go faster than flying birds (Mundal, 2000). It was previously thought that all the women remained behind in permanent settlements during the winter, so that they could see to the upkeep of any buildings or reindeer pens, while the men went off to hunt & herd reindeer (Mulk 1991). However, it is interesting to point out that stereotypical sex roles familiar to the European settlers did not exist in the same manner with the Sámi where females often carried out 'male' roles such as hunting (Mundal, 2000). The finding of late Iron Age/early Middle Age belt rings and distaffs, used for spinning and only worn by women, on known hunting routes are evidence of this asexual roles (Mulk 1991, 52). At the end of the winter period, the siida would split into family groups and move to their summer sites, which were constructed of pelt tents held down by stones and often used as a base camp for game hunting (Mulk, 1991). Game hunted included reindeer, moose and small game such as martin, otter, squirrel and beaver (Wheelersberg, 1991; Mulk, 1991; Aronsson, 1991).

The Sea Sámi, who utilised marine resources included fishing, whaling, sealing and walrus hunting (Eiremann, 1923), and whose occupations including trapping, hunting and fishing (Mulk, 1991), were noted as being culturally different to the mountain dwelling Sámi. In 1629 J. S. Stephanius commented on how much closer the Sea Sámi were culturally to the Europeans, with Peter Claussøn Friis (Skovgaard-Petersen, 2002) noting the distinct difference between the 'half-nomadic' Sámi and the settled Sea Sámi who were more reliant on marine resources (Meriot, 1984). These differences were also noted between the groups of Sámi themselves with the mountain Sámi referring to the Sea Sámi as Dáčâ, which meant an outsider or someone of non-Sámi behaviour (Paine, 1957). Adelaer also reported a complaint against the mountain Sámi, reported by the Sea Sámi, complaining that they had been encroaching on the Sea Sámi's land (Meriot 1984, 376). Both groups however had been known to keep limited numbers of livestock in the form of sheep, goats and reindeer (Broadbent, 2004), to carry out freshwater fishing (Mulk, 1991) and sealing (Meriot, 1984; Broadbent, 2004; Zorich, 2008).

Groups of the Sámi who began herding large numbers of reindeer would have benefited not only economically through trading the fur with the Europeans, but also nutritionally as the large numbers of tame reindeer would have provided a permanent meat and milk source (Mirov, 1945; Andersen, 2011). The large numbers of 'tame' does would have been regularly milked along with any goats kept, with each doe producing around half a glass of milk daily, which could then have been used to produce dairy products, cooked along with other products or drank (Mirov, 1945). Overall however the cultural activities associated with the Sámi would have had a low impact on the landscape and would have left limited 'trace' information in the soil cultural record.

1.5 Traditional European culture

1.5.1 History of farming in northern Sweden

Continuous and sedentary agriculture has been carried out along the Bothnian coast since the 6th century and was centred on animal husbandry and cereal production (Wallin, 1996). The introduction of new cultivation techniques in the form of cereal threshing and the casting of grains during the Iron Age would have generated higher harvest yields in spite of the deteriorating climate, may have been the reason for the expansion of sedentary farming into the Bothnian coast (Vorren, 1979; Wallin, 1996). There are, however, trace pollen records from several bog and lake cores in Norrland dating from BC 500-4000, suggesting cereal production, which is supported by archaeological evidence of agriculture in the form of grave sites and farm remains dated between BC 500-0 in the southern Norrland area (Wallin, 1996). According to pollen records the early (AD500-1200) cereal production was of barley, which was followed by an expansion of rye cultivation around AD1200 (Wallin, 1996).

According to Wallin (1996) initial cultivation is believed to have occurred in coastal areas, as well as along the river and lake banks, where natural hay meadows were present. The hay meadows are thought to have been the main factor when settling land between AD500-1500 as the hay was needed for animal husbandry (Baudou *et al*, 1991; Wallin and Segerström, 1994). It is however feasible that there were also small pockets of suitable land settled in peripheral regions (Wallin, 1996). The second desirable criterion for a potential settlement site was the existence of a *Picea* forest (Wallin, 1996). Spruce (*Picea*) forests tended to grow on the most fertile soils and so were the best option for future arable and pastoral farming (Huttunen, 1980; Segerström, 1990) with a large expansion in wood clearance visible in the pollen records during the 13th century (Wallin, 1996). The Norrland area saw further periods of agricultural expansion, especially between AD1600-1800 when agriculture assumed greater significance and areas of Ångermanland were colonised by Finns (Gothe, 1948).

1.5.2 **Traditional European 'farmstead' lifestyle**

Although land management techniques can vary from location to location, even over short distances, the main management techniques associated with European settlers in Norrland included slash and burn clearance techniques and manured topsoil's (Wallin, 1996). During the 17th century when settlement in inland Norrland was being encouraged by the Swedish government (Andersson, B. *pers. comm*), potential settlement sites were often cleared using slash and burn techniques (Gothe, 1948) where it may have been used as a one-time permanent clearance tool or for rotationally growing cereal crops (Wallin, 1996).

Barley (*hordeum*), which was one of the main cereals grown in Norrland, can only be cultivated on well worked nutrient rich soils (Englemark, 1981, 1991) so for the farmers to have a successful crop they would have needed to implement manuring techniques on the fields (Wallin, 1996). The addition of materials to the soil to create a more nutrient rich and deeper topsoil, also known as a ‘plaggen’ topsoil, is often associated with European settlements (Blume and Leinweber, 2004). The materials added could have included calcareous sand, grass or heather turves, manure, animal bedding, seaweed, leaf litter and household waste (Simpson, 1993, 1997; Blume and Leinweber, 2004; Hubbe *et al*, 2007; Davidson *et al*, 2007).

Most farms also kept livestock in the form of cattle and sheep, which were an important food source during the winter months both for meat and dairy products (Johansen and Vorren, 1986). In order to keep the livestock the farmer required winter fodder materials that were traditionally seaweed, if near the coast, and hay for the cattle and the bark, stems and twigs of birch, aspen and roan-trees *(Sorbus aucuparia)* for sheep (Vorren, 1979). However, farmers often relied upon fishing, both freshwater and marine, and the use of additional resources such as sealing and whaling, if near the coast, to supplement their crop yield and livestock (Johansen and Vorren, 1986) and additional activities such as forestry to generate extra income (Engberg, 2006).

1.6 Interaction

1.6.1 Why the Europeans settled in Sámi territory

Before interaction between the two cultures is discussed any further it is important to understand why Europeans began settling in Sámi territory. Small numbers of Europeans may have settled on the fringes of the Sámi territory to be closer to the trade source, i.e. the Sámi, or in search of viable farmland; however the main settlement period for this inland area occurred in the late 17th century (Andersson, B. *pers. comm*), during this period settlement occurred much further inland then previously seen as it was encouraged by the Swedish government (see figure 1.1 for a map of the study area showing the generalised settlement areas for the Sámi prior to European settlement, figure 1.2 for during the early coastal based settlement of the Europeans and figure 1.3 for the settlement area once inland settlement was encouraged); they offered incentives to potential settlers in the form of 15 years tax exemption and negation from army conscription (Andersson, B. *pers. comm*). During this period, a mixture of European nationals, including a large number of Swedes and Finns, settled in the historic province of Ångermanland, which borders Västerbotten and Lapland (Gothe, 1948). However small numbers of Sámi also took the opportunity and settled permanently in the area (Andersson, B. *pers. comm*). This encouraged period of settlement may have been one of the only opportunities for less financially well off peoples to obtain their own farmstead.

Possible reasons suggested for this encouragement of settlement in the Sámi territory included claiming the territory as Swedish, as it had been previously disputed between Russia, Finland and Sweden, to promote Christianity to the heathen Sámi and lastly, to gain better control over taxing the Sámi trade and therefore reaping better financial rewards (Andersson, B. *pers. comm*).

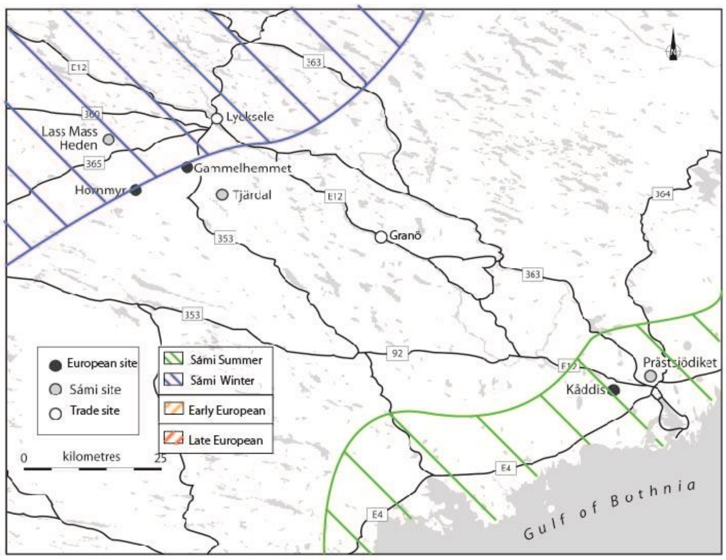


Figure 1.1: Diagram showing a generalised view of Sámi occupation boundaries at both winter & summer settlements prior to the settlement of Europeans

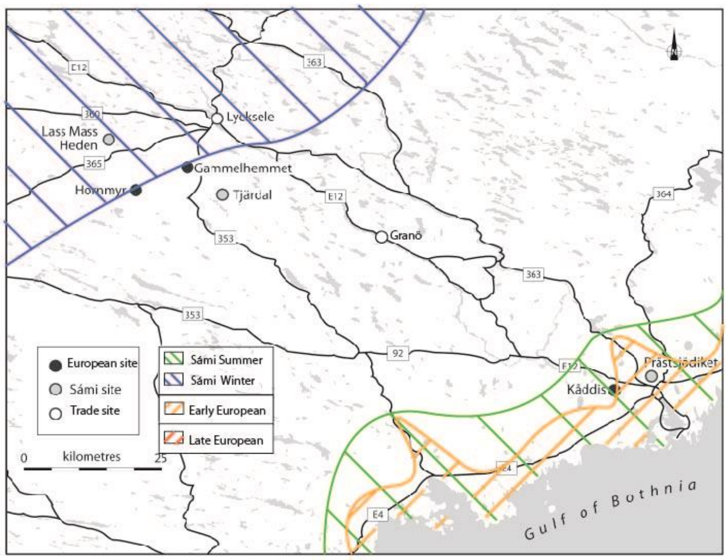


Figure 1.2: Diagram showing a generalised view of Sámi and European settlement boundaries during the 'early stages' of European occupation

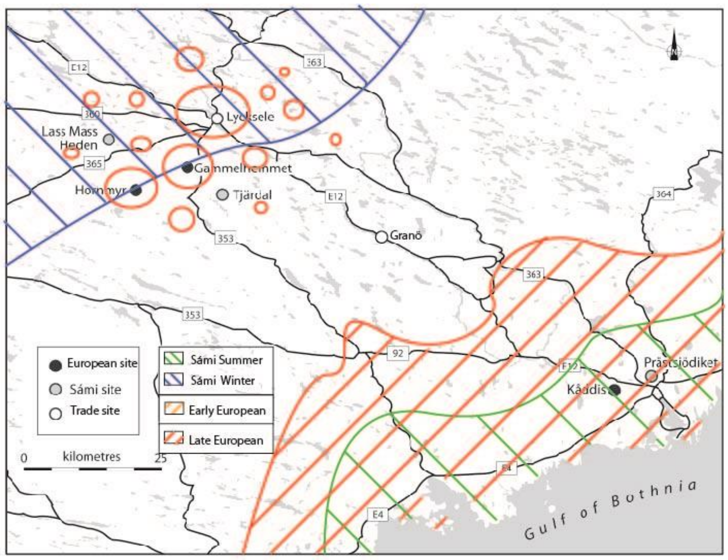


Figure 1.3: Diagram showing a generalised view of Sámi and European settlement boundaries during the 'later' stages of European occupation

1.6.2 **Opposing views**

There are two disputing arguments as to the type of relationship which existed between the Sámi and Europeans. One argument, the 'standard' view, is that the peaceful Sámi were suppressed, controlled and exploited by the aggressive Norwegians who taxed and plundered them for their goods (Olsen, 1999). The second argument, Odner's 'new' view, which has been widely accepted (Hofstra *et al*, 1995) and has archaeological evidence to support it, is that if the peaceful Sámi were being raided and plundered by the Europeans, they would make no effort to interact with them and would avoid them (Olsen, 1999). This would not have been beneficial to the Europeans who needed the Sámi for the exotic goods they produced and traded, i.e. furs, boats and metal ores, as well as their medical and spiritual advice (Meriot 1984; Hofstra *et al* 1995; Olsen, 1999), therefore it would have been in the Europeans interest to maintain a mutually peaceful relationship between themselves and the Sámi. Even though they were heavily taxed by the Norse for it, the trade was also beneficial to the Sámi (Wolf *et al* 1993; Hofstra *et al* 1995) as they were given butter and flour in exchange for their goods, as well as other products that they themselves could not produce (Kvist, 1992). These food stocks usually arrived during the winter, as travel was safest when the bogs and rivers were frozen (Bergman *et al*, 2006), which was the Sámi's lowest food supply period, thus removing a limiting factor and allowing a larger population to develop than previously possible (Kvist, 1992); this 'Economic cooperation' between the two cultures is believed to have begun between AD400-600 (Urbańczyk, 1992).

1.6.3 **Trade and tax relationships**

The most well know, and well documented, relationships between the Norse and Sámi were financial relationships of tax and trade *(*Nordstrom, 2000), with the tax taking the shape of bird feathers, animal skins, walrus tusks and ropes made from whale and seal skins (Meriot

1984; Wheelersberg 1991; Hofstra *et al* 1995). The Sámi in Sweden were taxed by Birkerlar, private business men who acted as collecting agents for the Crown (Muga, 1986), pre-11th century, but mainly during the 13th century (Wheelersberg, 1991), then by the state in the 14th century and finally by the Swedish King in the 16th century (Bergman *et al*, 2006). However from AD1550 onwards, trade was conducted at annual fairs at churches with there being a ban placed on Birkerlar being allowed to visit/trade with the Sámi at their camps for two reasons. Firstly, it gave the Swedish King more power over trade and two, as the official trade sites were at churches it was also used to try and convert the Sámi to Christianity (Kvist, 1992). The Sámi in Norway however, were heavily taxed by both the Norse and the church pre-11th century, with the Norwegian King taking more control of trade and taxation by the end of the century (Bergman *et al*, 2006,) and then also from the Russian monasteries that expanded into the White Sea area between the 14th and 16th centuries, who subsequently changed how the Sámi and Norse interacted and introduced new taxes (Bertelsen *et al*, 1988). Other financial relationships existed between the cultures in the form of work. Europeans such as Ottar (Ohthere), who was a "rich- Norwegian landowner, bailiff, and teacher during the reign of the Viking King Harald Haarfager (Pairhair) at the end of the ninth century" (Meriot, 1984, page 373) employed the Sámi to look after their reindeer as well as to carry out other basic labour jobs (Meriot, 1984).

1.6.4 **Trade centres**

The majority of trade between the Norse and Sámi in the early Norse medieval period was carried out at the Sámi's winter settlements, as it was safer for the Norse to travel across frozen ground rather than risk being caught in rivers and bogs (Bergman *et al*, 2006). The Europeans also constructed often very prestigious trade routes between their own and the Sámi's villages, firstly to ensure that once a safe passage was found, it could be recorded and reused and secondly, as a sign of their economic and political powers to other families as well as to the Sámi people (Bergman *et al*, 2006).

Long distance trade began with the Norse trading luxury goods for the upper classes, with the majority of the goods traded being slaves, furs, amber and ivory, to places such as Rome (Wheelersberg 1991). The objects they were exchanging these for were also destined for the upper classes and were items such as wine, honey and luxurious cloth (Hofstra *et al* 1995). At that time, trade was centred on the upper classes, as the peasants produced most of what they needed themselves and did not have surplus money for non-essential items (Wolf et al 1993). The furs originated from Sweden, Norway and Russia, with Norwegian explorers and merchants sailing far into the White Sea to locate the Russian furs (Wolf *et al* 1993). The Hanseatic trade organization, which was most effective in Northern Europe between 1250-AD1450 (Wolf *et al*, 1993), monopolised trade across Northern Europe from the 13th – 17th centuries through their alliance with trading cities and guilds (Awty, 2007) and were often competition for the Scandinavian traders as the Hanseatic merchant, such as the one which lived at the Kåddis site in the 14th century, resided in one place and organised their trade through a network of workers and contacts, thus allowing them to offer a larger range of products at often cheaper rates (Wolf *et al*, 1993).

Around AD1100 there was a commercial revolution in Europe, where people began to sell what they produced and buy the items they consumed from elsewhere (Dalton, 1967; Wolf *et al*, 1993), as well as large population expansions within continental towns meaning increased demands in dried fish (Hofstra *et al* 1995). This was also the time of the agrarian revolution in Scandinavia, where the technological side of farming leapt forward resulting in much more efficient tools (Wolf et al, 1993). They had also begun to transport bulkier goods by sea, instead of across land, meaning a quicker, cheaper and more efficient delivery system (Wolf *et al*, 1993). This meant that more everyday goods entered long distance trade (Wolf *et* *al*, 1993). Scandinavia then became a large exporter of fish and metals, but also in butter and meat (Wolf *et al*, 1993), with peasants using fishing in the Lofoten islands in Norway and iron mining in Kiruna and Malmberget, in northern Sweden, as secondary incomes to top up their revenue from farming (Wolf *et al*, 1993). The emergence of this new trade also effected the Sámi populations, as the increased demand for furs and metal from them, with a large number of traded goods originating from the Sámi in Lapland (Wheelersberg, 1991), led them to change their seasonal settlements as well as their economic and social habits, to accommodate the increased level of trade (Wolf *et al* 1993; Aronsson 1991) as in the Northern part of Lapland, the Sámi were involved in trading with the Norwegians, Swedish, Russians and any other travelling merchants from other countries (Wheelersberg, 1991).

During this period areas with rich marine resources underwent a change from a mixed subsistence farming way of living to having a much greater emphasis on fishing and the fish trade, with fish from its non-specialist individual farm households being traded for grain (Simpson *et al*, 2000). Examples exist of cereal cultivating areas, such as the Lofoten islands in Norway, trading in cereal for economic and personal gain rather than out of necessity (Simpson *et al*, 1998). The trading of items such as stockfish allowed the farmers to give up marginal agriculture and replace it with a more profitable alternative, in this case exchanging fish for grains and cereals from the South, especially Barley, oats and rye (Wolf *et al* 1993). This meant that they did not have to grow cereals themselves as well as allowing them the capacity to exchange the fish for other products (Perdikaris 1999); stockfish is an air dried cod, which must be 60-110cm in length with the heads removed, which requires no salt to preserve it; as the fish freezes at night and thaws just enough during the day to dry out without the fish rotting (Perdikaris 1999). Stockfish was an important commodity as it was promoted by the church as being clean ‘white food’, as well as being used by the military as rations due to its long shelf life of 2 years (Perdikaris 1999), with consumption of it having increased greatly since the end of the first millennium AD (Barrett *et al* 2008) it has been suggested that the stockfish trade became more valuable than the fur trade (Hofstra *et al* 1995).

Vågan, on the Lofoten Islands in northern Norway, was a prime operating spot to traffic the Sámi's fur and metal goods to Europe, and according to Inger Zachrisson acted as the 'economic cornerstone' for relations between the Sami and Western Europe due to its location near the rich Sami metal producing areas of Sweden; metal deposits included rich Iron ore and silver and were found in Kirunavaara, a mountain near Kiruna and in Malmberget (Bertelsen *et al*, 1988). This was an important relationship as the bog iron supplies available in Norway had become scarce during the middle ages, resulting in the iron ore from Sweden being traded down to Oslo at the end of the 13th century (Schia, 1994). Sweden also had a greater wealth of raw materials, such as forests and charcoal, needed to produce iron so it was more economical to manufacture the iron in Sweden and trade it through Norway's international trade sites (Espelund 1985).

1.6.5 **Spiritual and medical advice**

Pre-Christianity, the religious beliefs of the two cultures were thought to have been similar (Olsen, 1999) with selected Europeans seeking medical and prophetical advice from the Sámi, as well as asking for blessings and safe journeys (Meriot, 1984). When Christianity was accepted as the main religion of the Scandinavian countries, Law's against Europeans seeking any of the above Heathen advice were introduced. This was to try and reinforce the new Christian values (Mundal, 2000), with anyone suspected of seeking advice or prophecies to have their supplies and equipment seized (Meriot 1984). However many Europeans still sought after this advice with Tore Hund, an associate of the famous Norwegian adventurer Ottar, who travelled for two winters across Sámi territory around AD890 so that he could have his reindeer fur jacket blessed by a Sámi Shaman, believing that it would then be "more invincible than breastplates" (Meriot 1984). Subsequently the Swedes were accused of using Sámi witchcraft during periods of war (Mundal, 2000). The Sámi's medical remedies were also sought after and were viewed as being such high quality that they were collected and documented before being taken abroad (Meriot 1984).

1.6.6 **Marriage**

There are also written records of mutual cultural and genetic exchanges having occurred (Kvist, 1992) in the form of marriages between the Europeans and Sámi. This could either be to settle disputes (Mundal, 2000), or between the rich and social elite of the two cultures (Hofstra *et al* 1995; Olsen, 1999) as Sámi brides were viewed as exotic (Mundal, 2000).

1.7 Literary evidence of culture change due to interaction

1.7.1 **Domestication of reindeer**

The origin and date of reindeer domestication is still a highly debated topic (Bjørnstad *et al*, 2012) with three different views relating to the origin still in consideration. Wiklund (1919) supposed that domestication occurred independently in four different areas, Hatt (1919) and Maksimov (1928) theorized that the Lapp's domesticated reindeer independently to the domestication of reindeer in Southern Siberia and lastly Laufer's view (1917) that reindeer were domesticated in southern Siberia and the knowledge of domestication was passed onto the Lapp's (Mirov, 1945; Vainshtein, 1980). Each is a possibility. Recent work into ancient DNA has revealed distinct groups of reindeer in Fennoscandia and Russia which has been attributed to independent domestication (Røed *et al*, 2011; Bjørnstad *et al*, 2012), thus supporting both Wiklund and Hatt's views. As a result and as the Sámi were known to keep small numbers of tame reindeer before any large scale domestication occurred

(Bergman *et al*, 2006; Meriot 1984; Aronsson 1991) the author is inclined to go with Wiklund or Hatt's arguments.

As there are references discussing the overlap in territory between the Samoyed, known reindeer herders, and the Lapp (Sámi) culture, an exchange of knowledge leading to the domestication of reindeer by the Lapp's is plausible (Mirov, 1945). However as this overlap in territory was noted in the late 15th century, almost 800 years after the first documentation of tame reindeers in Scandinavia (Aronsson, 1991), it is more likely that there was another trigger, which led to the large scale domestication of reindeer.

It has been to some extent theorized that the increased demand in reindeer fur for the European trade market led to the large scale domestication and herding of reindeer in Scandinavia (Mulk, 1991). However, this increased demand in furs could and was met through increased hunting (Urbańczyk, 1992, 63). Work on extensive areas of fangstgropsystemer, reindeer pit traps, by E. Manker (1960, cited in Urbańczyk 1992) in the mountains of Scandinavia was the background for E. Badou's 1981 theory that the appearance of these features was evidence of the intensified exploitation of the mountainous interior by the Sámi as a response to the increasing fur demands by the Norse (Urbańczyk, 1992). It is possible to assume that different groups of the Sámi responded differently to this increased demand in fur with some groups increasing hunting activities and others developing herding practices, however it is also important to consider the outside influences on the Sámi. The Sámi, who traditionally never kept more than a few tame reindeer to act as decoys and attract wild reindeer when hunting (Aronsson, 1991), may not have come across large scale animal domestication until they were introduced to European culture through trade. It is therefore plausible that the trigger for keeping large numbers of reindeer in herds was the increased demand in fur for the European market and the idea of herding had resulting from seeing how European settlers kept their livestock in herds, therefore the relation to the domestication and herding of reindeer can be related to interaction between the cultures in two ways.

Andersen's work (2011) into differentiating between reindeer herding and reindeer hunting activities may be used to distinguish between the use of the Sámi sites studied i.e. pastoral or hunting. Hunting based occupation sites would have been located away from the reindeers grazing territory, in order not to startle the reindeer, where-as herding based occupation sites would be located close/within the grazing area (Andersen, 2011). A distinction between the disposals of reindeer bones after meals was also identified. It was believed that the gods were capable of 'putting new flesh on the bones' of eaten animals so it was important to leave behind the bones, skin and if applicable, the antlers of the animal (Bradley, 2000: 8). The herders would bury the bones in pits near the occupation site and cover them with sand and stones to prevent the bones injuring grazing reindeer, whereas reindeer hunters would have left the bones *in-situ* (Andersen, 2011). Therefore buried bones indicate hunters and discarded bones indicate herders (Andersen, 2011).

1.7.2 **Coastal Sámi**

The distinguished difference between the Sámi who lived near the coast who often traded and interacted with the Norse on a more regular basis, and the Sámi who dwelled in the forests and the mountains (Meriot 1984, 375) was highlighted in section 1.3, Traditional Sámi culture, but will be further explored here as the cultural change of the coastal Sámi is related to interaction with the Europeans.

The coastal or Sea Sámi effectively developed a new sub-culture, taking aspects from both the European and Sámi cultures (Manker and Vorren, 1962). They still moved seasonally to hunt and fish in different areas, whaling, fishing and boat building out on the islands during the summer, before moving back inland during the autumn to hunt reindeer, but no longer following the reindeer migration pattern and instead keeping tame reindeer to bait wild reindeer when hunting (Manker and Vorren, 1962). However the degree to which the supposed dependence and interaction reached is debated, with modern literature generally depicting less than the older literature. The growing cultural differences between the coastal and mountain Sámi, such as speech, dress and etiquette, led to the 'mountain' Sámi, who were predominantly reindeer herders, effectively turning their back on those who interacted with the Norse regularly, referring to them as Dáčâ; meaning an outsider or someone of non-Sámi behaviour (Paine, 1957).

The Helgøy project showcases a group of Sámi who developed differently, culturally speaking, and are believed to have been much more Europeanised than other Sámi groups, including the Sea Sámi groups discussed (Mathiesen *et al*, 1981). The Sámi from the Helgøy region in Northern Troms, Norway, were fluent in Norwegian and are believed to have co-existed with the Norse from the early 13th century (Bratrein, 1981) until the 18th century (Mathiesen *et al*, 1981). Interdisciplinary studies of the project have speculated that a regular nomadic pattern would have been "very unlikely" (Mathiesen *et al*, 1981, 85) in the area and the Sámi instead had a similar economy to the Norse (Mathiesen *et al*, 1981).

1.7.3 After the Black Death

Between 1300 and 1450 agrarian populations decreased rapidly in relation to the Black Death, climate change and war, which caused farm prices to drop and the number of deserted farmsteads to increase (Abel, 1980; Vorren, 1979). With an estimated population decrease of up to 58% in Sweden in relation to the Black Death, it has been suggested that post-AD1350 large numbers of those settled in Norrland moved back down to Southern Sweden (Antonson, 2009). As the Sámi population were not as affected by the plague as Europeans, as they were in the mountains and avoided contact (Urbańczyk, 1992), it allowed some Sámi to take over sedentary European roles and either move into abandoned farmsteads or be employed as farm hands by the remaining Europeans (Urbańczyk, 1992). In coastal areas of Norway it was also noted that the Sámi became involved in stockfish trade after the Black Death (Urbańczyk, 1992). This implementation of European style activities by the Sámi was encouraged by the settled Europeans as it would have helped in rebuilding the economy (Urbańczyk, 1992). However pollen records still indicate a period of agricultural recession in the form of greatly reduced numbers of cereal and sorrel pollen between 1350-AD1440 which indicates that even with the adoption of European activities by the Sámi there was still a marked impact on agricultural activities in Scandinavia (Vorren, 1979; Van Hoof *et al*, 2006). Although this cultural change is directly related to the Black Death rather than interaction between the cultures, this change over of roles, whereby members of the Sámi became directly involved in European style practises and the fact that they were welcomed to do so by the European population, was only possible due to the interaction of the cultures previous to the Black Death; whereby each culture had a basic understanding of the other and as they were already interacting through trade the adoption of cultivation by the Sámi was a logical next step for both cultures on account of the circumstances.

1.7.4 **Christianity**

The relationship the Sámi had with Christianity has been commented on briefly in the last section (1.6 Interaction), with Europeans being forbidden from seeking heathen spiritual advice from the Sámi once Scandinavia accepted Christianity and the Sámi having to trade at designated annual church fairs, such as at Lycksele, from AD1550 (Mundal, 2000; Meriot 1984; Kvist, 1992).

The Sámi were also encouraged to accept Christianity and had to attend church 5-6 times a year at specific holidays; Christmas, Easter, Pentecost (after Easter) and four prayer days in

April, June, July and August; however in 1730, the dates the Sámi must attend church were changed in order to fit better with reindeer herding activities (Andersson, B. *pers. comm*). During this period, priests were sent into Sámi territory to convert the Sámi to Christianity (Wiklund, 1923; Andersson, B. *pers. comm*). However, as most priests were reluctant, and occasionally refused, to move into Sámi territory some Sámi were selected to be trained as priests (Wiklund, 1923). This resolution was also seen as beneficial to the cause as it was believed that the Sámi would convert more easily if the priest was of a Sámi origin (Andersson, B. *pers. comm*). This push for conversion will have affected the Sámi directly and indirectly. Those trained as priests will have been directly affected from the adoption of Christianity by Sweden as they exchange their traditional lifestyle, dress code and daily routines, but the remainder of the culture will also have been affected; through regular attendance at church and the banning of their own religious practises. Even for those Sámi who were not successfully converted to Christianity the imposed church attendance and restricted trade sites will have affected them. The attendance at church will have influenced the migration patterns of the semi-nomadic mountain Sámi. Even with the altered attendance dates post-AD1730 (Andersson, B. *pers. comm*), the restriction on trade out with the annual church fairs, may also have effected them financially; possible financial implications include costs such as time and money associated with transporting trade good to the church sites, as well as the lowered value for trade goods due to the market being flooded as all Sámi from the same region had to attend the same trade fair. The noted lapse in traditional practises, such as making offerings to the gods, during the 17th and 18th century by the Sámi indicates the slow dismissal of traditional practises as a result of this push towards Christianity (Bradley, 2000).

1.8 Summary

To summarise, the Sámi have been identified as a largely semi-nomadic, hunter-gatherer population who engaged in low impact activities such as foraging, fishing, hunting and at later stages, reindeer herding. Asides from the culturally distinct Sea-Sámi and those who accepted employment as farm hands or in the fish trade after the Black Death, no cultivation was practised by the Sámi with crops and other goods being obtained through trade with the Europeans. This indicates that any impact on the soilscape by the Sámi will be any localised effects from the burning in the hearths, related to the reindeer and/or occupation areas. Impacts related to the reindeer would include increased phosphorous levels from their manure, localised compaction and erosion of the soil on migratory routes or milking and pen areas. Impacts associated with the occupation sites will be associated with the felling of trees for burning and construction which may have led to erosion of the exposed areas and compaction at and around the cots.

The Europeans have been identified as relying primarily on arable cultivation and trade. Therefore their footprint on the landscape is likely to be cultivation based. The impact of plaggen style soil formation on the inherent podzolic soils will be well marked, with changes in soil depth and chemistry being expected along with compaction and homogenisation of the ploughed layer. Out of the different forms of interaction between the cultures discussed, the only possible direct impact on the soilscape would be through the adoption of reindeer herding or arable cultivation by a previously hunter-gatherer group of Sámi.

The identification of any Sámi impact, or proof of the adoption of European style activities by the Sámi, will provide a new approach to their footprint on the landscape. As the impact of hunter gatherers in marginal areas is still a relatively unexplored area, this thesis will provide new insights into the impact on the soilscape This will then complement existing studies such as the impact on the vegetation by Renouf *et al* (2009).

Chapter 2: Soils

2.1 Podzol soils

2.1.1 Formation of podzol soils

Podzol soils cover an estimated 485 million ha worldwide, roughly 4% of the world's surface, and are defined by the World reference base for soil resources (2006) as "soils with a typically ash-grey upper subsurface horizon, bleached by loss of organic matter and iron oxides, on top of a dark accumulation horizon…" (91). Podzols are typically found in the boreal and temperate zones having formed under acid vegetation such as heather and coniferous forest, and are extensive in Scandinavia, but they can also form in the tropics under light forest (WRB, 2006). They form from medium to coarse textured acid parent materials, which has a clay content of 35% or less such as siliceous bedrocks, glacial tills, alluvial and aeolian deposits of quartzite sands, but will from on any parent material in the boreal zones (WRB, 2006; 91). Gley and organic soils form in very similar environments, with the exception of the waterlogged conditions, therefore organic and gley soils are often in depressions within a podzol landscape (Conry & MacNaeidhe, 1999).

Podzols form through various chemical and biological processes. The main processes involve the weathering of the primary mineral components, the decomposition of organic material, cheluviation processes, whereby clay minerals are attacked and broken down and alluviation/illuviation process (Kanev and Kazakov, 2005). The alluviation process is when any soluble organic matter and mobile iron (Fe) and aluminium (Al) are leached from the upper layers of the soil (A-horizon) to the lower horizons (B-horizon) and illuviation is when the organic matter (OM), Fe & Al particles accumulate to form discrete layers in the B-horizon; known as the spodic horizon (Kanev and Kazakov, 2005). These layers are rich in humus and Fe and can cause water-logging in the above layers as they can limit water percolation through the layer; Al often forms another layer below (Jansen *et al*, 2002; 2004).

After the majority of the soil constituents have been leached from the upper horizon, a new horizon will be left, known as the E-horizon and/or albic horizon**,** where the main component left will be quartz grains which give the horizon a bleached white/grey appearance with little soil structure (Buurman & Jongmans, 2005).

An example of a podzol soil is shown in figure 2.1 where below the root mat a dark organic layer can be seen, followed by a light grey E-horizon where the majority of OM, Fe & Al has been leached down the profile to form the orangey brown B horizon below; the profile shown is a control profile from Sweden which was located under a pine & birch forest with no known anthropogenic uses. The undulating E and B horizons are likely to be the result of freeze/thaw movement of the soil or from preferential water drainage routes; it is unclear without chemical analysis whether the profile has a Bhs horizon, high in Fe & Al with patches of organic matter (OM), or a Bs horizon, high in Al + Fe but low in OM.

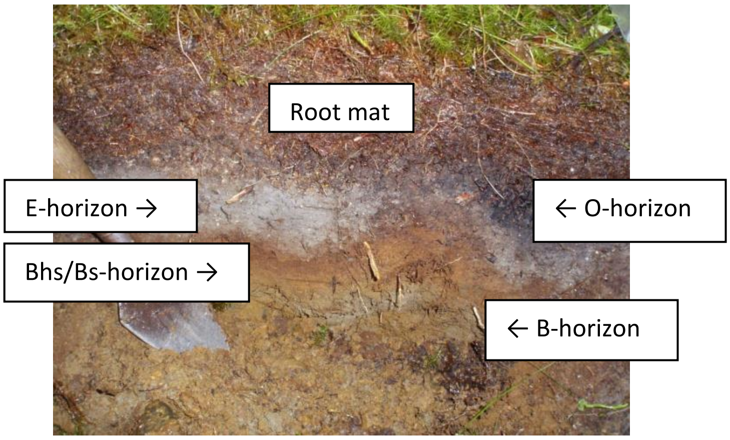


Figure 2.1: Annotated photograph of podzol soil in Tjärdal, Sweden

Al and Fe are vital to the acidification and pedogenesis processes and although they can both be toxic to soil organisms and vegetation if present in too high a level, Fe is an essential element and needs to be present in lower concentrations (Jansen *et al*, 2002). There are two Iron fractions that are important in the understanding of podzol soils, Fe(II), which is associated with anaerobic conditions and Fe(III), which is associated with aerobic conditions (Jansen *et al*, 2002).

Dissolved organic matter (DOM) can influence the biological availability and mobility of Fe and Al, and can form stable complexes, known as stable ring structures, with the Fe(II), Fe(III) and Al(III) fractions (Jansen *et al*, 2002). However, the translocation of Al and Fe in podzol soils can be affected by the amount of dissolved organic matter (DOM) present, as when the Al and Fe binds to the DOM to form organo-metal complexes, the mobility of both is affected and it prevents the formation of in-organic Al and Fe phases (Jansen *et al*, 2004). The bonding of Al^{3+} and Fe^{3+} to the solid-phase OM can make the OM more polar, therefore increasing the solubility of previously hydrophobic organic molecules in water (Jansen *et al*, 2004). If and once the Fe and Al are desorbed from the solid-phase OM, the Al and Fe are re-mobilized. OM itself can also be mobilised by the detachment from solid soil materials and the higher the levels of Al and Fe present in the soil, the more OM will be mobilised to compensate (Jansen *et al*, 2004).

The metal to organic matter ratio (M/C) can be affected by the percentage of Al, Fe and DOM, which has adsorbed onto solid soil materials and this will, in-effect, determine whether or not any organo-metal complexes formed are organic or inorganic (Jansen *et al*, 2004). Petersen (1976), De Coninck (1980), Mokma and Buurman (1982) believe that organo-Al, Fe and DOM play a major role in the mobilization, and subsequent eluvial movement down the profile, of Al, Fe and DOM, however this view is opposed by Farmer *et al* (1985) and Anderson *et al* (1982). Complexes can also form to be soluble or insoluble, influenced by the pH and M/C ratio of the soil, which will influence how the complex can move as in the case of insoluble complexes, the mobility of the metals is limited as is the mobility of the DOM they are adjoined too (Jansen *et al*, 2004).

The length of time needed for a podzol to form, including how long it takes for a podzol to become visually recognizable, how long it takes for a spodic horizon to form and whether the podzol should meet certain colour or chemical criteria, or both, to be classed as a podzol is still a debated topic. The World reference base for soil resources maintain that a spodic horizon takes around 4,780 years to form (WRB, 2006), this standardised time period is highly disputed in favour of a more requirement based estimation involving the parent soil and location. The more individualised estimates of podzol horizon formation vary greatly from Singleton and Lavkulich (1987), estimating 370 years for a podzol to form on a sandy beach in Canada, Protz *et al* (1984) calculating that 1900 years would be needed for eluviation/ illuviation processes to become evident, Barrett and Schaetzl (1992), who think between 4,000-10,000 years would be needed for a spodic horizon to form in Michigan, and Juahiainen (1972), who thinks it would only be 100-350 years for a chemically differentiated podzol to form in Lapland (Mokma *et al* 2004).

The time needed for a podzol to form depends on the criteria used to define whether the soil is podzolic or not. This argument dates back to the late 1970's when McKeague *et al* disputed the chemical criteria that Soil Survey Staff were using to identify podzolic soils as too strict. They analysed 220 pedons (units of soil) from Canadian podzolic soils and found that 60% of them did not meet the necessary chemical criteria to be classed as podzols (McKeague *et al*, 1983). Disagreements over the strict criteria podzols must meet is still an issue with Mokma *et al* (1992, 2004) finding that although a podzol can meet the colour requirements of being a podzol within 230 years, it can take a further 5,540 years for it to meet the chemical criteria required (Mokma *et al*, 2004). He calculated that only 50% of the soils he studied in Michigan met the Al and Fe concentrations required and less than 10% met the optical density of oxalate extract (ODOE) criteria (Mokma *et al*, 2004). However, with their being other soils similar with similar properties to podzols, such as Albeluvisols, and other horizon types similar to the spodic horizon, such as sombric & plinthic horizons which are very similar with the exception that a spodic horizon will have a much higher cation exchange capacity (CEC) of the clay fraction and more vermiculite & Al-interlayed chlorite, so a possible counter argument is that if the strict guidelines were reduced it is possible that these horizons could be mistaken for each other.

2.1.2 Podzol model

Several anthropogenic activities and how they impact on podzol soils, or can lead to the formation of one, have been discussed in the following sub-sections. The knowledge gained from this has been used to form a podzol model, summarising the effects of each activity in a flow chart (see figure 2.2).

2.1.2.1 Fire

Forest fires whether started naturally by lightening during a summer drought (Czimczik *et al* 2005, 417) or started anthropogenically, either intentionally for clearance or accidentally, causes a massive disturbance to the forest floor as it changes the fractional soil composition and the physical and chemical elements temporarily (Beskorovainaya and Tarasov, 2009). Some of these changes take place almost instantly such as the conversion of Carbon to CO_2, CO and CH_4, of nitrogen to NO_x and N_2 and sulphur to $SO_{2,}$ which are then lost to the atmosphere (Czimczik *et al*, 2005. 417), as well as the reduction and/or change in composition of the organic matter (Czimczik *et al* 2005, 417) plus the extreme temperatures experienced in the soil rooting layer that cause a moisture deficit in the soil for up to two years following the fire (Beskorovainaya and Tarasov, 2009). Other changes include an increase in the pH level of the underlying E-horizon, which means that it may reach above the 4.5 required to be classed as a podzol (Czimczik *et al*, 2005 418). There may also be a reduction in the original number, and diversity, of invertebrates living in sandy podzol soils, in addition to a continuation of the original moisture deficit through an increase in ground insolation through the amount of solar radiation the ground receives; due to the removal, through burning, of any ground vegetation and leaf litter, therefore exposing the soil (Beskorovainaya and Tarasov, 2009).

There are also long term changes connected with forest fires. One is caused when the trees, and any other vegetation, become disconnected from the nutrient cycle. This is through the decreased infiltration rate associated with the movement of volatised hydrophobic organic compounds, which can cause a permanent change in plant composition (Kristiansen, 2000), the other is a direct result of all the other changes mentioned which can lead to a profound alteration of the soil properties and for that reason, a possible change in soil type (Beskorovainaya and Tarasov, 2009). On the other hand, it is believed that the fire may release nutrients that could potentially increase soil germination, consequently aiding tree regeneration, and although prescribed and controlled burning, around every 5 years, will still affect the long-term soil properties of under lying podzols, they are thought to only affect them vaguely (Kristiansen 2000, 32). However it must be noted that the degree of severity that these changes happen depends upon the intensity, duration and numbers of fires endured (Czimczik *et al*, 2005). For instance, the conversion of organic matter to black carbon, the greater the frequency of fires occurred in an area and the higher the organic matter content of the soil (Czimczik *et al* 2005). However, the more intense the fire, the higher the percentage of the organic layer is consumed in it, therefore leaving little carbon left to be converted; black carbon forms through the incomplete combustion of organic matter (Czimczik *et al* 2005, 417). Therefore, if the fire is less intense, it will only partially consume the organic layer meaning that more organic matter is available to be converted into black carbon (Czimczik *et al* 2005). Frequent fires are also associated with the increased transfer rate of organic matter form the organic layer into the mineral layer of the soil (Czimczik *et al* 2005).

2.1.2.2 Creation of plaggen soils

As podzolic soils were not highly suitable for agriculture (WRB, 2006), plaggen soils were often created. Studies by Jørgensen (1994) showed that ploughing can immediately affect podzols soils as the topsoil can be mixed with the underlying eluvial horizons, therefore removing the characteristic structure of the podzol and allowing compaction to occur (Kanev and Kazakov, 2005), it can decrease the air and water conductivity values of the soil and an essential supply of fulvic acids can be destroyed when the top layer of plant debris is removed; fulvic acids can affect the acidity of the podzol (Ivanov, 2000). However if the soils is regularly ploughed the top ‘plough layer’ can become homogenised and any gleying processes will be exaggerated (Kanev and Kazakov, 2005).

Ploughed soils typically have a thinner eluvial zone when compared to untouched forest soils, which subsequently means a reduced rate of clay and oxide movement (Kanev and Kazakov, 2005). This is also considered to be the reason why there are higher rates of nutrient loss, excluding iron, magnesium and calcium, in forest soils than when compared to ploughed soils (Kanev and Kazakov, 2005).

The bulk density of the soil, which can affect its drainage capacity, temperature and nutrition regimes (Kuznetsova *et al*, 2009) can be altered by how regularly the soil is ploughed as although ploughed soils will have a higher bulk density value than forest soils, if the soil were to be ploughed on a very regular basis the bulk density would actually improve to a reasonable level (Kanev and Kazakov, 2005). This is important as if the soil is not regularly ploughed the bulk density will increase, therefore decreasing its water drainage capacity and subsequently increasing the wetness of the soil. This will, in turn, increase the bulk density value of the soil (Kanev and Kazakov, 2005). The bulk density value can reach a point where it becomes a limiting factor, causing vegetation to struggle to grow with crops such as barley, being unsuccessful (Kuznetsova *et al*, 2009). However a slightly elevated bulk density level is not always a negative, as the higher the bulk density of the soil, the less it will suffer from compaction (Kuznetsova, *et al* 2009). Kanev and Kazakov (2005) has demonstrated that ploughing a soil will increase its humus content, which leads to an increase in its carbon stock of up to twice that of a forest which was shown, through correlations, to be linked to the increased carbon input above ground through leaf litter and any post-harvest residues and roots (Kanev and Kazakov, 2005).

The addition of manure to a soil can greatly increase its organic matter content, which in turn stabilises the humus and structure of the soil plough layer making it less susceptible to erosion (Kuvaeva *et al*, 2001). It will also increase the nitrogen (N), phosphorus (P), Iron (Fe), aluminium (Al), potassium (K), magnesium (Mg), sodium (Na), calcium (Ca) and sulphur (S) content of the soil as they are the main components of organic matter (Kuvaeva *et al*, 2001). However, some of these, particularly organic carbon (OC), N, K, Ca, Mg, S and a fraction of the P, can be uplifted by plants and then lost through cropping, or through natural decomposition, or leaching processes (Kristiansen, 2000). In homefields and any other locations where there has been a concentrated addition of manure, the humus layer would be much thicker, with a higher organic matter content as a result, and the soils chemical properties would be more positive than in any other improved croplands; as well as a more stable soil structure than in any unimproved soils (Kuznetsova *et al*, 2009).

2.1.2.3 Other activities: Grazing, charcoal burning and tree felling

Areas where animals were grazed, even if they were not originally podzolic, will begin to podzolise (Madsen, 1983). This is often caused by the change in vegetation to un-palatable species which are resistant to trampling, such as heather and bracken, which are acidic in nature and can increase the acidity of the soil (Goudie, 1990). Kristiansen (2000) also found that podzols will form directly underneath old charcoal pits, and believes that this is linked to the enhanced infiltration rates and changes in the organic matter and/or iron form in the soil which occurr as a result of the charring process above. A further cause of transformation in podzolic soils is through the decreased evapo-transpiration rate associated will tree felling. This will cause podzolic soils to become over moistened, which will facilitate gleying (Kanev and Kazakov, 2005); Cruickshank and Cruickshank (1981) have also suggested that when heathland grows on deforested land a Bhs horizon can develop within 200-300 years.

2.1.2.4 Abandonment of cultivated soil

There are also detrimental effects associated with abandonment where the soil has either been exhausted of its nutrients or suffers from the discontinued application of fertilisers (Litvinovich *et al*, 2002). On ex-arable land that has been abandoned, pioneer vegetation will grow, usually herbaceous perennials, which will help stabilise the soil for up to 3 years; however after that period negative changes in the humus will occur (Litvinovich *et al*, 2002). The soil will become more acidic and the carbon content will decrease, lowering the total carbon content of the soil by up to 5.6% (Litvinovich *et al*, 2002). Over the next twenty years, the agro-chemical properties of the soil will continue to deteriorate with a decrease in base saturation and the optical density index plus a sharp drop in the nutrient content of the soil; due to there being no more in-put of fertilisers and the loss of the remaining nutrients through percolating water (Litvinovich *et al*, 2002). The podzolisation is thought to have been caused by the export if nutrients when the crops were removed and then followed by the invasion of acidic heathland when the ground was abandoned (Kristiansen, 2000).

2.1.2.5 Summary

Podzols form naturally, but also as a side effect of a variety of human activities, and can be influenced and transformed by a selection of processes as summarized in the model (see figure 2.2). The model outlines the maximum modification anticipated with anthropogenic activities so thought must be given when considering less intense variations of the activities as although changes to the soil will occur, they may not be adequate to alter the podzol to another soil type. It is important to note that podzol soils undergoing human influence that do change soil type tend to change in two main ways, either becoming a cultural soil that is of value to those occupying it, or into a gley soil that would be of low use and value.

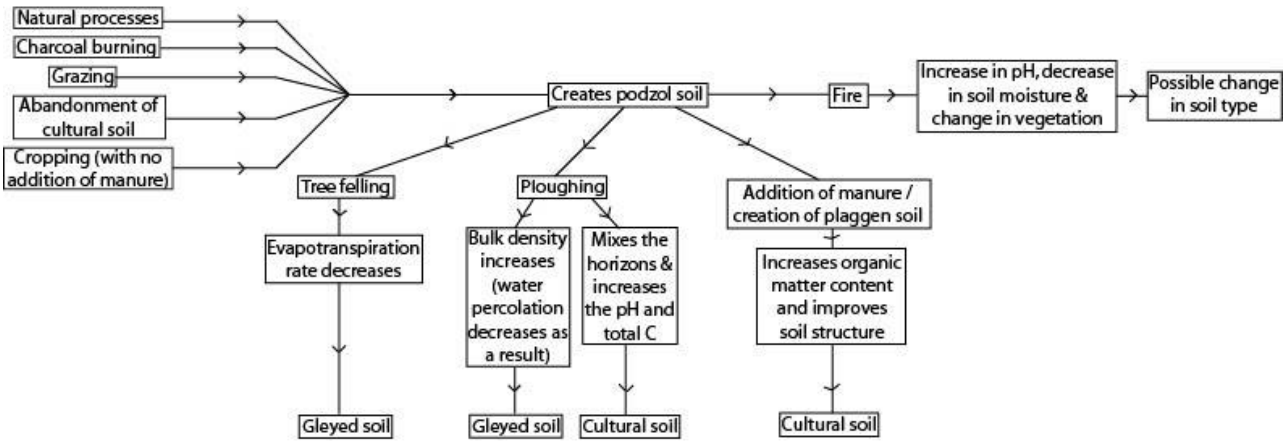


Figure 2.2: Podzol model

2.1.3 Anticipated effects related to traditional Sámi land use

Site specific soil maps have returned a base podzol soil for all sites (SGU, 2011). However, as mentioned in section 2.1.1 gley and organic soils, such as peat, often form in depressions and water logged areas within podzol landscapes (Conry and MacNaeidhe, 1999). As a result, a mosaic soil type is often present but overlooked by large scale soil mapping due to the size and localised nature of any gley or organic areas.

Looking at traditional Sámi activities there would be no significant alteration to an existing podzol soil type with the exception of the traditional hearths in occupation areas, tree felling and possibly grazing activities related to the reindeer herders. Any change in soil type related to fire as noted in the podzol model, figure 2.2, would only occur in localised areas directly underneath and surrounding the hearths.

Trees would have been felled by the Sámi in order to obtain the raw materials for the construction of cots as well as for necessary equipment such as boats, skis and sleds (Aronsson, 1991). As detailed in the podzol model, the removal of trees can result in reduced evapo-transpiration rates, which in podzol soils can alter the conditions enough for gleying to occur. However, due to the extensive forests in northern Sweden it is unlikely that the trees felled by the Sámi would have had more than a localised impact on the soil, if any at all.

The development of podzol soils through overgrazing of reindeer is unlikely as the existing soil type is typically podzolic to begin with. In areas where there may be other soil types present, it is unlikely that grazing reindeer would have had enough of an impact to create the conditions needed or podzol soils to develop; however, podsolization may have occurred in areas where the reindeer were concentrated such as pen and milking areas.

2.1.4 Anticipated effects related to traditional European land use

Anticipated effects on already established podzol soils in relation to European activities include almost everything covered in the podzol model i.e. changes from charcoal burning, grazing of livestock, tree felling, ploughing, the addition of manure, the creation of plaggen topsoils, cropping, fire and the abandonment of cultural soils.

As the sites being studied are farm based settlements, it would be unlikely for them to have their own charcoal pits. However, clearance activities such as slash and burn when first settling the land would have involved tree felling and fire, which could have led to the formation of podzol soils on any non-podzolic areas. As all of the study sites are mapped as having podzolic soils, any further development of them in an existing podzol mosaic landscape would have a minimal impact on the overall area.

As podzol soils are acidic with low nutrient availability and moisture holding capacity, as well as potentially suffering from aluminium toxicity, they are unsuitable for arable agriculture unless improved (WRB, 2006). In order to improve the soil for cultivation, the water holding capacity has to be increased, any hard illuviation horizons or iron pans need to be destroyed and the soils must be deeply ploughed and fertilised (WRB, 2006). As a result, cultivation activities such as ploughing, manuring and creating plaggen topsoils are to be expected at each of the European sites. In accordance with the podzol model, these activities will 'improve' the soil in that the original podzol horizons would have been mixed giving the soil a better pH balance and re-introducing carbon to the upper horizons, the addition of manure and creation of plaggen topsoils would improve the soil structure and the increase the organic matter content of the soil making it more productive agriculturally speaking.

Yet, without adequate attention, the anthropogenic soils can easily develop back into podzols. If the farmers did not apply sufficient amounts of manure and other fertilisers, after cropping or in areas of intensive grazing, podsolization would begin to occur returning the soil to its natural state. Both of which are possibilities at the study sites. The other change to the land management regime that would bring a large impact to the soil is abandonment of either the site or the manuring activities.

2.2 Anthropogenic soils

2.2.1 Formation of anthropogenic soils

Anthropogenic soils are defined by the World reference base for soil resources (2006) as “soils that have been modified profoundly through human activities, such as addition of organic materials or household wastes, irrigation and cultivation” (71), and include more specific soil types such as plaggen soils, which will be the soil type concentrated on in this study, and can form from almost any soil type with the right input of materials (FAO, 2006).

For an anthropogenic soil to be classed as plaggic it has to meet certain criteria, which as outlined by the FAO (2006) includes a texture of sand, loam or a combination of both, having between 1-20% artefacts and/or spade marks present at a depth of 30cm or more, a munsell colour of 4 or less with a chroma pigment of 2 or less when moist, an organic carbon content of ≥0.6%, a thickness of ≥20cm and occurs in locally raised surfaces (FAO, 2006;32).

Plaggen soils have positive physical soil properties such as high porosity and water holding capacity but often have negative chemical properties such as nutrient deficiencies and acidity (FAO, 2006). Plaggen soils typically occurred in areas where the resident soil was nutrient poor (Davidson *et al*, 1984) and had low productivity levels (Conry and MacNaeidhe, 1999). The plaggen topsoil was created gradually through the application of materials, such as heather and grass sods, manure and forest litter (Conry and MacNaeidhe , 1999), which replaced the nutrients removed through cropping (Creutzberg *et al*, 1988) and fertilised the soil (Hubbe *et al*, 2007). The heather and grass sods were typically removed from podzolic soils from ‘waste-land’ areas surrounding the arable fields and when cut would often have part of the mineral horizons removed with them (Simpson, 1993). This addition of mineral material is the reason for the typical depths of +1m seen in plaggen horizons (Davidson *et al*, 1984; Blume and Leinweber, 2004.). Although plaggen management techniques was believed to have originated in north-west Europe during the Bronze-Age and spread geographically across Europe (Blume and Leinweber, 2004), radiocarbon dates and archaeological finds from a plaggen soil in Tofts Ness, Orkney and which have been dated to 4000 BC is currently the earliest known example of this soil management regime (Simpson, 1995).

Although plaggen topsoils have been found across Britain, Ireland, North West Europe and recently in European Northern Russia (Hubbe *et al*, 2007), the formation processes differ slightly from location to location with relation to the materials applied. In the Netherlands, Germany and Denmark the main input were turves, with preference being given to heather turves as they absorbed more manure, and forest litter (Blume and Leinweber, 2004). Both turves and heather would have been used as animal bedding (Blume and Leinweber, 2004) with farms in Northern Germany mixing heather sods with between 1/20th to 1/3rd manure and leaving the mixture to decompose in mounds for weeks to months during the summer to create manure (Blume and Leinweber, 2004). Davidson *et al* (1984) and Simpson (1993, 1995) documented that in Orkney, plaggen soils were formed through the application of seaweed, both fresh and partially decomposed, calcareous sands, ash, manure and turves. The turves will have been used as animal bedding over the winter and would have been added in the spring after they had dried out and become saturated with animal manure (Davidson *et al*, 1984; Simpson, 1995). In 1999, Conry and MacNaeidhe documented that the main input into the plaggen soils found in the Dingle Peninsula of Ireland was marine sand that was either added directly as a liming agent or after it had been used as animal bedding and had incorporated some of the animal manure.

The time needed for plaggen topsoils to form is unclear and would be dependent upon the volume and type of materials added as well as ploughing practises on site. As the depth of the anthropogenic horizon needs to be ≥20cm to meet the criteria outlined by the FAO

(2006), a considerable period of time would be required; SAR's for studied plaggen topsoils in Orkney by Simpson (1993) were estimated at between 0.8-0.9mm per year.

2.2.2 Plaggen soils model

Anthropogenic soil names and types, as classified in the FAO (2006), include plaggen soils, paddy soils, terra preta do India, Agrozems, Terrestrische anthropogene Böden, anthroposols and anthrosols (FAO, 2006); although this study focuses on plaggen soils, only formation processes associated to those soils will be discussed and used in the model.

The traditional processes associated with the formation of plaggen topsoils have been discussed above and added directly to the model, however there are also processes that can revert the positive soil physical changes. This will either allow the plaggen topsoil to return to its original state or develop into a less agriculturally useful soil type such as podzol or gley soils. Some of these negative processes include over cropping without adequate replacement of lost nutrients, overgrazing and soil compaction from large numbers of livestock, soil compaction from over-ploughing and the abandonment of an anthropogenic soil either completely or through the cessation of manuring practises (Goudie, 1990; Kristiansen, 2000; Litvinovich *et al*, 2002). Most of the data discussed for the podzol model is also relevant here in that plaggen soil formation is one of the methods of altering a parent podzol soil; see figure 2.2 for podzol model and figure 2.3 for plaggen model.

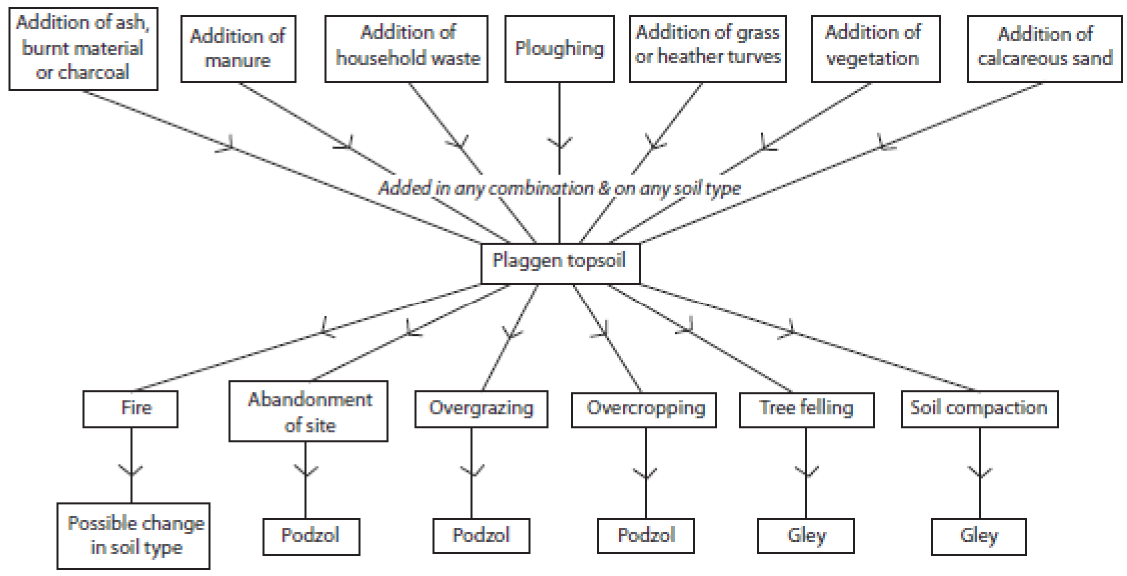


Figure 2.3: Plaggen soil model

2.2.3 Anticipated effects related to traditional European land use

The anticipated effects on the natural podzol soils at the European settled sites is that through ploughing and the addition of a variety of different materials, as outlined in the plaggen soil model (figure 2.3), a plaggen soil will have developed. Soil micromorphology analysis will help identify organic matters added to the soils.

As slash and burn clearance techniques, as well as slash and burn rotational farming systems, have been recorded in Sweden it is likely that it was employed as a clearance technique at the study sites as well as possibly being used for rotational crop growing (Gothe, 1948; Wallin, 1996; Andersson, B. *pers. comm).* If slash and burn was used only as a clearance technique, especially as it would be teamed with tree felling in order to clear the area for cultivation, with the fire being sustained long enough to alter the soil properties and commence a change in soil type, it would presumably have been a short lived change as in accordance with the model the plaggen management techniques employed in order to transform the inherently infertile podzol soils into culturally viable soil would have altered the soil type into a plaggen soil regardless of the original, or in this case secondary, soil type.

Due to the long-time scales associated with soil change and formation a visible change in soil type from the original podzol to one altered by the fire before the anthropogenic plaggen soil began to develop would be extremely unlikely.

There is the possibility that over grazing, over-cropping and soil compaction occurred either individually or in a combination at any of the European settlement sites. Once the anthropogenic plaggen soil has formed any of these activities could have negative consequences in that the soils could either begin re-podzolising or gleying. Due to the northerly latitude of the sites crop production would be marginal at best so over-cropping would be unlikely, especially with the continued addition of 'plaggen' materials to the soil replacing any lost nutrients (Fageria *et al*, 2002). On the other hand as the site is marginal any small changes could be extremely detrimental to the soil and could be enough to begin repodzolisation and gleying processes even if they would not ordinarily be enough to begin changes in a more temperate climate. The likelihood of overgrazing and soil compaction at the sites is again possible due to the fragile soil conditions associated with marginal areas (Pierce *et al*, 1983; Schneider & Fry, 2005). However as livestock numbers kept at each site are unknown, although as fishing was a commonplace additional activity to farming with meat and food products also being available through trade (Wheelersberg, 1991; Wolf *et al* 1993) the author envisages small numbers of livestock being kept at the sites, overgrazing and soil compaction from livestock are expected to be minimal; due to the occupation periods being studied soil compaction from farm machinery is negligible.

Chapter 3: Methodology

3.1 Introduction

Soils and sediments retain information from the environment that they formed under including evidence of past environments and any anthropogenic modification; either intended or unintended. By identifying and understanding the differences between un-modified soils and those which have been anthropogenically altered, any changes can be detected. These changes, alongside other analysis of the soil, i.e. studying the soil stratigraphy and chemical analysis, can be used to identify and interpret the past land use/land management systems. Radiocarbon dating, alongside the careful interpretation of the soil stratigraphy and on-going and historic soil processes, can be used to set the identified past land management regimes in chronological order.

This chapter will set out the methodology behind each step of the study from the research design through to the analysis.

3.2 Research design

The research design was tailored so that the aims and objectives identified in chapter 1 could be achieved. Objective 1, 'to identify and review key information for each culture' has been carried out throughout chapters 1 and 2 through the review of key literature, however further planning is needed in order to achieve objectives 2 to 4; to establish what cultural indicators are retained in Scandinavian soils, to establish which of these cultural indicators are associated with Sámi and/or European activity and to use this knowledge to identify interaction between the cultures.

In order to establish which cultural indicators are retained within podzolic and anthropogenic soils, in addition to establishing which are associated with Sámi and or European activity and identifying areas of interaction, Sámi and European sites with Podzolic and anthropogenic soils had to be identified. Sites were identified with the aid of documented archaeological surveys and local knowledge, from archaeologists at the Skögsmuseet, Lycksele, academics at Umeå University and local landowners, prior to leaving for the field; the majority of information on Sámi sites was limited to the presence of hearth stones.

Once sites were identified a sampling strategy was established. Due to the historic nature of several of the sites, the natural variation of the underlying soils and the reduction in impact from the area of settlement (Simpson, 1997; Wilson *et al*, 2005), a five profile transect starting from the estimated occupation area and heading into the hinterland was settled on. The final two profiles on the transect are to be located within the hinterland and will act as control samples for the site; the profiles within the transect will be set at intervals of around 20m but due to natural variation and obstacles, in addition to obtaining two control samples per site, exact distances of 20m was impossible however all profiles are mapped in the corresponding site sections; see chapters 4 and 5.

Note: Due to the close proximity of the Sámi site Prästsjödiket and the European settlement of Kåddis, the two control samples described at Kåddis also act as the control samples for Prästsjödiket. A sixth profile was also exposed underneath a clearance cairn at Hornmyr so that fossil soils could be sampled.

3.3 Study locations

3.3.1 Profile sampling

The soil transects started at the estimated occupation site and extended out into the hinterland with the final two profiles being used as control samples as planned in the research design; estimated occupation site was identified through visual presence of hearth stones at the Sámi sites and where available, through local knowledge at the European sites (see figure 3.1 for visualisation of transect). The soil profiles were dug until the B horizon was exposed, with a face being cleaned up prior to a detailed stratigraphy being drawn up. This face was then sampled with visible charcoal fragments being removed for later radiocarbon dating before soil samples were collected. Due to the limited number of kubiena tins available kubiena and bulk soil samples were collected from each horizon from at least one of the occupation profiles and control samples and from the A and/or anthropogenic horizon of the remaining profiles; kubiena samples were collected before bulk with all samples being collected from the bottom of the profile to the top. Where the soil horizon was wider than the kubiena tin the sample was collected from the centre of the horizon, with additional samples being collected at the bottom of the anthropogenic horizon at the European sites when this was not captured by the first kubiena tin. The bulk soil samples were collected from the centre of each horizon. Soil profiles were then described according to their colour and texture.

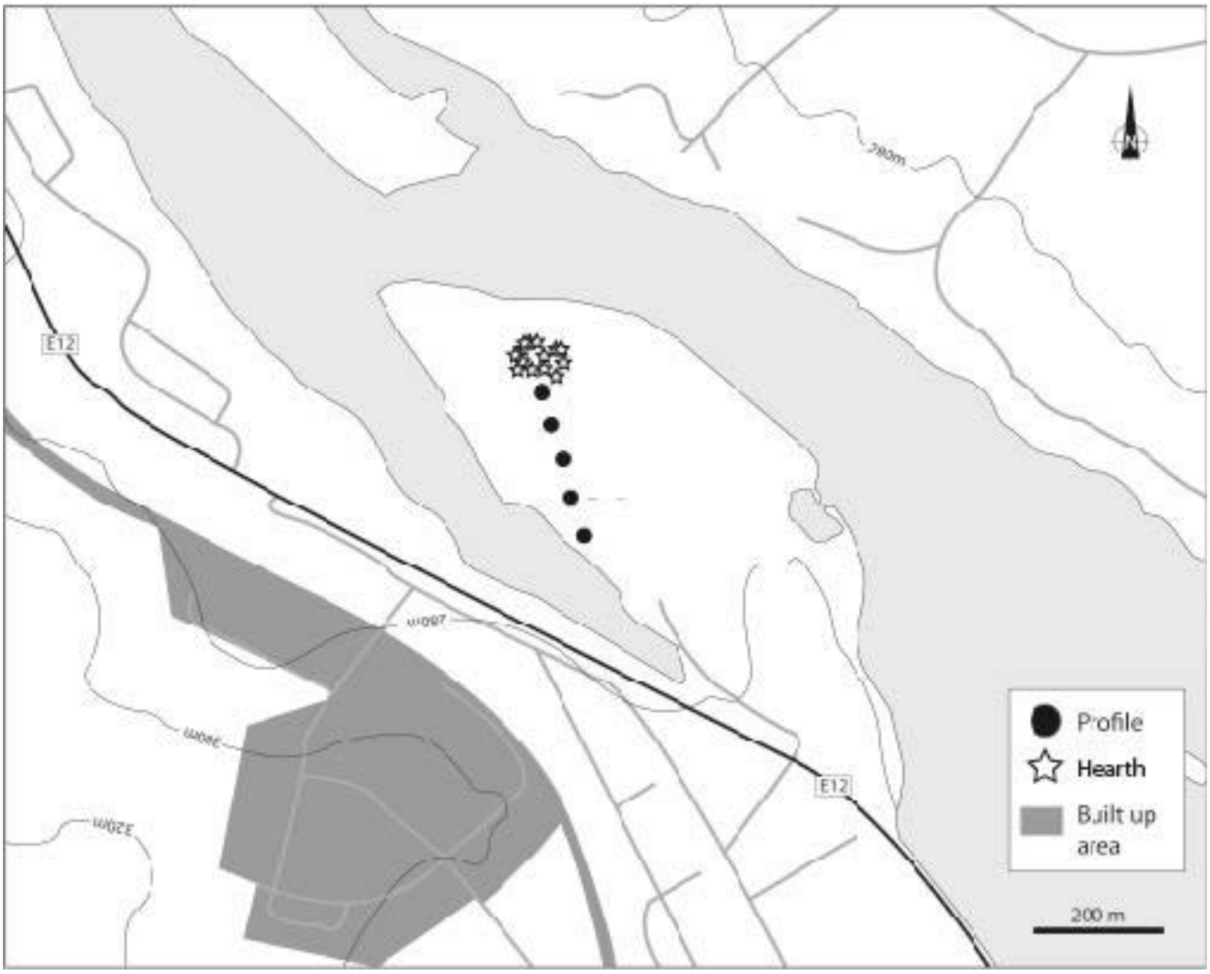


Figure 3.1: Visualisation of 5 profile transect leading out from activity areas into hinterland

3.3.2 Environmental information

The study sites are all located in the Västerbotten County in northern Sweden and can be grouped into two geographical areas. Firstly the coastal sites of Prästsjödiket (Sámi) and Kåddis (European), located near the city of Umeå, and also the inland sites of Lass Mass Heden and Tjärdal (Sámi) and Hornmyr and Gammelhemmet (European), which are located near the city of Lycksele; see figure 3.2 for location map. The base soil type throughout northern Sweden and at each site is podzol (see table 3.1) with accompanying boreal vegetation; see figure 3.3. The coastal sites are situated on sedimentary bedrock, with the inland sites, with the exception of Hornmyr, being situated on an acid to intermediate intrusive rock; Hornmyr is situated on basic intrusive and volcanic bedrock (Swedish Geological Society, 2010); see appendixes 1 to 5 for geology maps. All sites were covered by the Weichsel glacier which retreated and melted around 9,600 years ago, giving a maximum soil formation period of 9,600 years, with the rising land rate currently being estimated at 8 mm per year, having risen 285m since the glacier retreated, due to isostatic recovery (UNEP, 2011).

The nearest river to all of the sites is the Ume Leven however there are several lakes throughout the area which are closer to certain sites than the Ume Leven. Table 3.1 contains a variety of site information which includes the distance from the centre of the site to the nearest water source, either a lake or the river Ume, as the crow flies. All of the Sámi sites are located within 1km of a water source which indicates that close proximity to fresh water was a key component when identifying settlement sites. The distances to the nearest 'official' trade site have been calculated along modern day roads as they were often build on old tracks and rights of way but of course must be considered with discretion. The 'official' trade sites are Lycksele for the inland sites and Umeå for the coastal sites however as the age of the Sámi sites are unclear it is also worth noting the distances to Granö; Granö was the official trade site prior to it being moved to Lycksele in AD1607 (Andersson, B. *pers. comm*). As they are all considerably closer to either Lycksele or Umeå, see table 3.1, it would suggest that these sites were in use post-AD1607 however the sites would have been occupied in different seasons, coastal summer settlements with winter settlements in the interior, and although the post-AD1607 markets can be dated, trade prior to this is complex so as a result assumptions on settlements being chosen in relation to trade markets cannot be made.

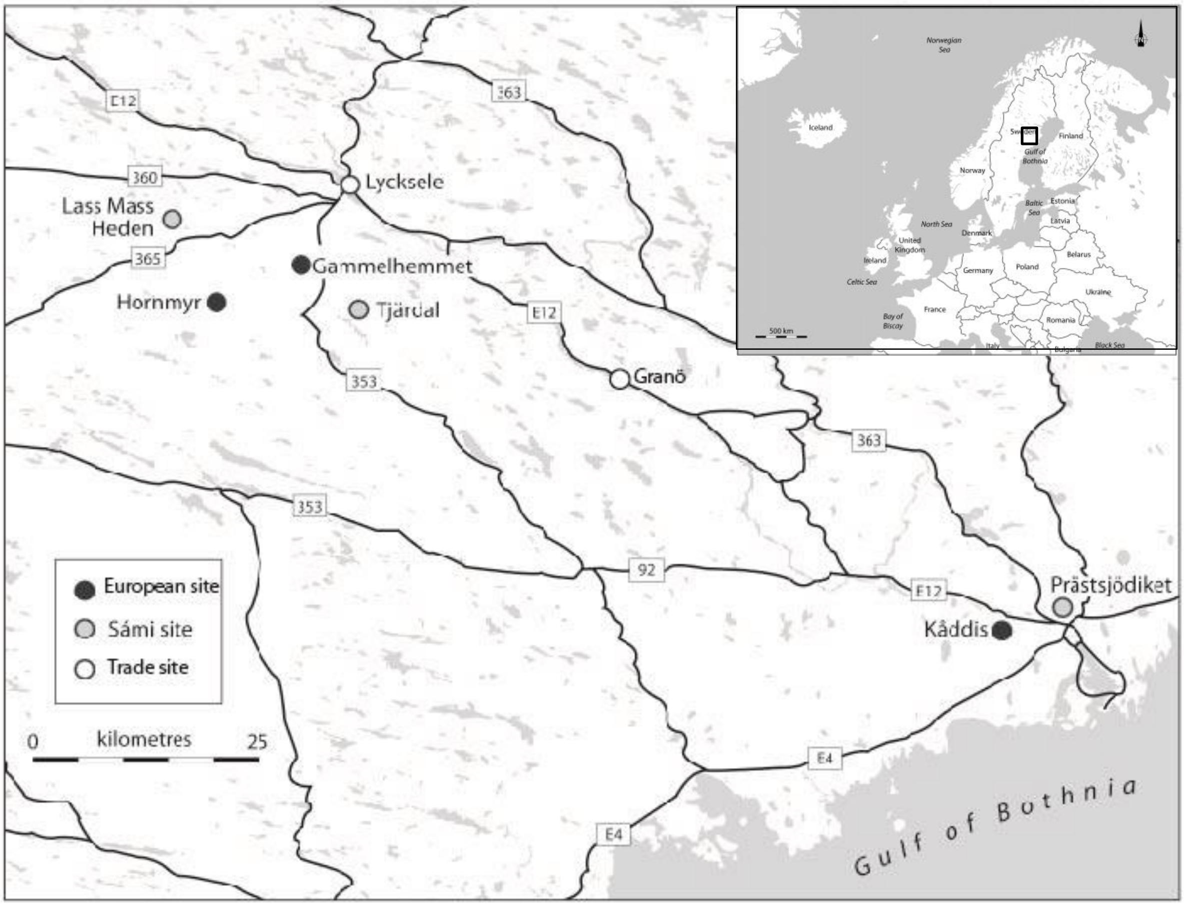


Figure 3.2: Map showing location of all study sites in addition to early (Granö) and late (Lycksele) trade sites

Gammelhemmet and Kåddis are located within 1.5km of the nearest water source however the nearest current water source to Hornmyr is currently 8km away. The distances to the nearest 'official' trade site have been calculated along modern day roads as they were often build on old tracks and rights of way but of course must be considered with discretion. The 'official' trade sites are Lycksele for the inland sites and Umeå for the coastal sites.

Table 3.1: Basic environmental site information (bedrock and soil types obtained from Swedish Geological Society 2010, distances calculated using Google Maps 2010)

	Site name	Bedrock	Soil type	Distance to nearest 'official' trade site	Distance to Granö trade site	Distance to nearest water source
Sámi	Prästsjödiket	Sedimentary rock	Podzol	7.3km	67.3km	<0.5km
	Lass Mass Heden	Acid to intermediate intrusive rock	Podzol	23km	74.8km	1km
	Tjärdal	Acid to intermediate intrusive rock	Podzol	26km	58.2km	0.5km
European	Kåddis	Sedimentary rock	Podzol	9.9km	N/A	0.5km
	Gammelhemmet	Acid to intermediate intrusive rock	Podzol	24.1km	N/A	1.5km
	Hornmyr	Basic intrusive / volcanic rock	Podzol	42.9km	N/A	8km

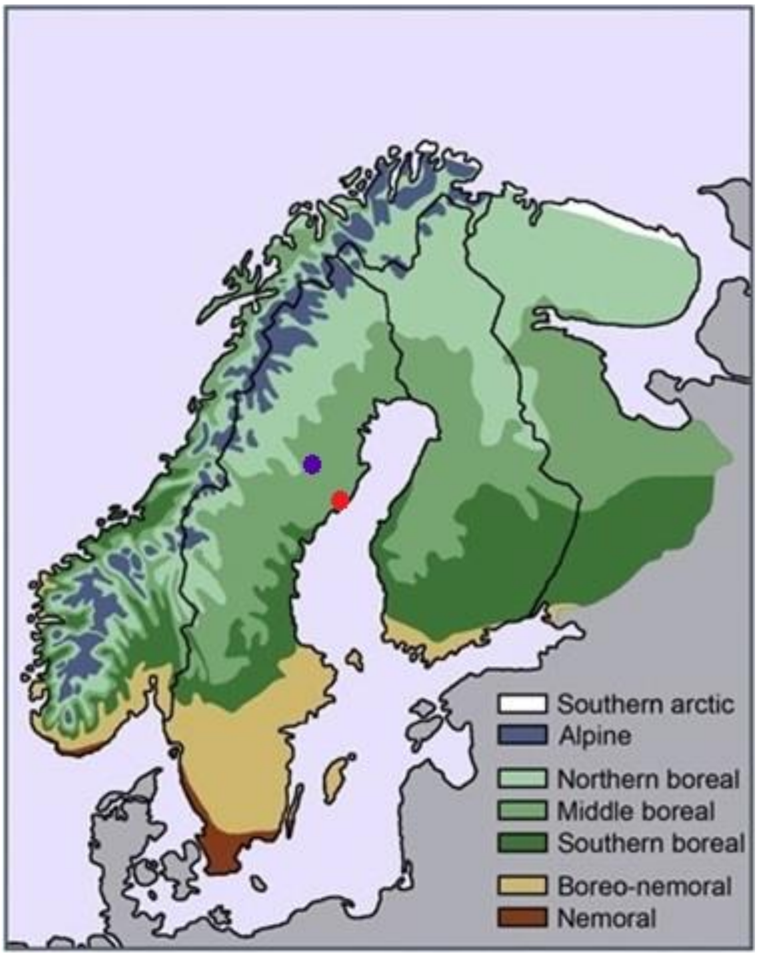


Figure 3.3: Generalised vegetation map of Scandinavia showing study sites to be located within Middle boreal zone; red dot indicates coastal sites and purple dot indicates inland sites (Moen, 1999).

Kåddis and Gammelhemmet are both located within 1.5km of the nearest water source and within 9.9km and 24.1km from the nearest official trade site respectively (see table 3.1), indicating that proximity to a water source had priority when looking for a settlement site. Hornmyr however does not follow this rule and is located 8km from the nearest water source (see table 3.1). The distance to a fresh water source should be a negative factor when identifying a new settlement however as all sites were covered by the Weichsel glacier the land will have uplifted 285m since the glacier retreated (UNEP, 2011). Therefore there may have been fresh water sources much closer to the Hornmyr site which have subsequently dried up or changed course due to the uplift of the land.

3.4 Lab methodology

3.4.1 Chronology

Chronology is either relative, where events are looked at in a sequence, or absolute, where each event has a specific date. Absolute dating is essential when it comes to calculating past events however relative dating, in the form of looking at the sequences of events, is also useful in establishing land use and pattern change. Radiocarbon dating will be used as a relative dating tool in this study so that any phases of activity identified can be set into a chronological order.

Radiocarbon dating is the measurement of the unstable isotope C^{14} which is produced by cosmic rays in the upper atmosphere before it diffuses down as CO_2 and becomes incorporated into all living organisms via photosynthesis and the food chain (Lloyd, 2002). It is an essential dating tool as it can be used to date a large variety of organic carbon containing samples such as charcoal, bone, shell and wood (Kovar, 1964; Anderson *et al*, 2007), and can give an accurate date to within one Standard Deviation of the mean (Roberts, 2000). This is especially helpful when the sample has originated from an area where there are little or no historical documentation and no other ways to date a find. It is also very useful in dating and understanding mixtures of finds, i.e. in a midden or if the sample has been disturbed and has subsequently moved into a younger or older soil.

3.4.1.1 Associated problems

There are several problems associated with radiocarbon dating in relation to soils. First is the sample size, as until the 1980's samples needed to contain a large enough amount of Carbon to be analyzed, however with the introduction of AMS dating, samples as small as 5mg could be accurately dated (Roberts, 2000).

Another problem is that of contamination of samples. Contamination can occur naturally by the growth of roots down through an old soil resulting in a 400 year old soil containing 5 year old roots, to the careless addition of new carbon to a sample by the researcher by touching or dropping something into the sample (Roberts, 2000). It must also be taken into account that the sample being analysed is a contaminant of the study area, i.e. it may be a very old or young sample that had been washed downstream and ended up in the study site and is not representative of the age of the study site (Coleman and Fry, 1991). Therefore each sample must be adequately pre-treated before being analysed.

The main inaccuracy that could occur is related to the dating of vegetation samples that can give misleading dates. This is because, for example in the case of wood, a tree can live for several hundred years. Therefore the age of the heartwood tree rings at the centre of the tree (the oldest part) can be significantly older than the outer sapwood (newer tree rings). This is because unlike animals, trees have a different and short lived cell structure where-by after a period of time the cells in the older wood will die and the connecting tubes will cease to be used, therefore stopping the intake of C^{14} to that part and allowing the C^{14} contained within it to start decomposing which is why in old trees the tree can appear to be healthy on the outside but be rotten and/or hollow on the inside (Kovar, 1964). This means that depending upon which part of the tree is dated, a large variation of dates can be achieved from the centre heartwood giving the date when the tree first grew to the outer sapwood where it would be the date the tree died (Kovar, 1964).

The next two problems associated with dating trees are to do with the younger, outer tree rings being destroyed, therefore making it impossible to find the date the tree died. The first is when a tree is burnt, the outer sapwood is usually worst affected and turned to ash, whereas the inner heartwood is more likely to remain as charcoal (Coleman and Fry, 1991). Therefore if it is found at a site and radiocarbon dated it will come back much older than the actual death of the tree, and possibly older than the time of the fire; if the tree had died and remained untouched for a long time period before it was burnt (Kovar, 1964). The second problem relating to the removal/destruction of the outer tree rings are when wood that is used for posts and building purposes are trimmed and shaped before use, possibly eliminating the younger sapwood. Even if it is not removed the outer sapwood can often rot away over time leaving only the inner, older heartwood and finally, wood samples can often be trimmed down before dating to remove any possibility of outside contamination, however this again will leave the older heartwood, therefore giving an older date (Kovar, 1964). Therefore any radiocarbon dates from vegetation samples such as wood need to be given appropriate consideration as, if a much older date due to the sample coming from the heartwood of a tree was overlooked, it could create an inaccurate chronology and void any further work.

Moving away from the dating of plant macrofossils, beetle fragments will also be dated so the problems associated with their dating must also be addressed. The species of beetle to be dated is of importance as some beetles are known to burrow down into the soil which will provide a younger date than the surrounding soil (Khorasani, *pers. comm*). Until recently the school of thought on the reliability of AMS ^{14}C dating of beetle fragments was that they would return younger dates (Hodgins *et al*, 2001); however recent studies have shown a consistency between the ages of beetle sclerites and plant-macrofossils (Porch and Kershaw, 2010).

Finally there are problems relating to the location of the material to be dated, in this instance within the soil. The soil will be reworked by biota through processes of bioturbation (Tonneijck and Jongmans, 2008) which can move datable material down profile, but also depending upon the size, up-profile (Carcaillet, 2001). Root disturbance, frost heave and illuviation, all processes anticipated at the study sites, are also known to affect datable material by disrupting the soils horizons and contaminating deeper soils with contemporary carbon (Esdale *et al*, 2001; Tonneijck and Jongmans, 2008). If the dated material is located within the root growth area, which would therefore be subject to bioturbation and root growth disturbance, then there may be an underestimation in the date (Orlova and Panychev, 1993). Bearing this in mind the dating of suitable material within soil is still of importance as even if displaced, it still dates the burning event.

3.4.1.2 Charcoal sampling and processing

Charcoal samples in key locations which could further the understanding of key processes were selected for dating. Once the proposal for their dating was accepting the selected charcoal samples were identified and weighed by S. Ramsay (2009, *pers. comm*) before being prepared and dated using the AMS method at the NERC Radiocarbon Laboratory in East Kilbride, Scotland. All calibrated radiocarbon ages were calibrated using the University of Oxford Radiocarbon Accelerator Unit calibration programme (OxCal 4.1) and the IntCal 09 calibration curve.

3.4.2 Bulk samples for pH and magnetic susceptibility

The bulk soil samples collected were air dried over a two week period prior to being sieved through a 2mm brass sieve. Any beetle or charcoal fragments within the bulk samples were extracted via tweezers and stored as back up radiocarbon dating material. This material was then used for calculating the pH and magnetic susceptibility values for each soil horizon.

The pH was calculated using a Hannah instruments pH209 meter. 5g of the dried soil sample was added to 25ml of distilled water in a 50ml beaker and stirred rapidly until all soil particles were suspended. The solution was left to settle for 20 minutes before the pH readings were taken. The pH meter was calibrated prior to use and again between each site's samples using pH4 and 7 buffers.

The magnetic susceptibility was calculated using a Barington MS2 system with an MS2B dual frequency sensor. The system was calibrated using a control sample of known magnetic susceptibility and recalibrated between each sites samples. As the mass specific magnetic susceptibility was desired the sample pots of known mass ($10cm^3$) were used. The sample pots were weighed empty, and again once filled with the dry soil sample on a calibrated lab scale prior to being entered in the Barington system. The susceptibility values were taken at both low and high frequency levels but returned low readings. Consequently air readings were taken before and after further readings at a low frequency so that any drift could be corrected. The mass specific susceptibility was then calculated using the formula $\chi lf = \kappa/\rho$ (χlf = low frequency mass specific susceptibility, κ = volume susceptibility and ρ = bulk density). All samples were tested consecutively in one day with the temperature of the lab being kept constant throughout sampling.

3.4.3 Thin section samples

The kubiena samples collected in the field were returned to the thin section laboratory at Stirling University. They were prepared according to Murphy 1986 by the author, with the final cutting, lapping & polishing of six of the samples being completed by the author with the remainder being completed by the resident technician, G. MacLeod; Logitech lapping plates (LP50 & LP40), Buehler saws (Petrocut, Isomet 5000 & small Isomet) and Logitech CL40 Polishing plate were used. The kubiena blocks were impregnated with polyester resin and left uncover-slipped so that X-ray fluorescence (XRF) analysis could be carried out with a Scanning Electron Microscope (SEM).

3.4.4 SEM

3.4.4.1 Reliability of XRF chemical analysis

XRF analysis was chosen over wet chemistry of bulk samples due to the more its more precise nature. The micro-scale of the areas that can be chemically analysed using XRF means that key features and fine horizons can be chemically tested which would be missed, or the reading hidden/diluted if a bulk sample was used.

The chemical data output from the XRF analysis is given as a percentage weight i.e. the percentage of the each element out of the whole. This means that due to individual variances the percentages will vary slightly depending on the background information of each sample i.e. a set weight of phosphorous in two different samples could produce a slightly different percentage depending upon the background concentrations of the other elements analysed. Due to natural variation not every profile and or site has each horizon and/or micro-stratum type and for those that do, the numbers of each horizon, as well as the elements present within these, varies greatly. The bulk of the elemental concentration was carbon, oxygen and silicon which are key components of the local mineralogy, as well as the resin used in the production of the thin section slides, so these were removed from all analysis as were sulphur and nickel which were only rarely picked up; the % concentration of the remaining elements is all below 3%. Nitrogen, sulphur and manganese were not normally distributed due to their low frequency within the samples and as such have not been calculated.

Software to convert the XRF percentage output into estimated weights is available but is still inaccurate (Macphail, R. *pers. comm*). As the samples all originate from podzol or podzol based soils and due to the inaccuracies associated with converting the data it was decided that the original percentage weight output would be used for statistical analysis rather than converting the data into estimated weights.

3.4.4.2 Sampling strategy

A Zeiss EVO MA15 SEM machine was used to calculate the percentage weights of each element. As it was not possible to analyse the entire stratum a 3 point sampling strategy was employed so that three areas within each horizon were sampled and averaged to get the most accurate representation. The samples were taken diagonally across the stratum to maximise the type of area sampled, for example samples could be taken from the top right-hand corner, the centre and lower left hand corner of each horizon. Due to the undulating, thin and frost heaved nature of the horizons the size and location of the three sample areas varied from horizon to horizon; see figure 3.4 for a representative photograph showing the areas analysed from the organic, charred, E and B horizons of slide 2A at Lass mass Heden.

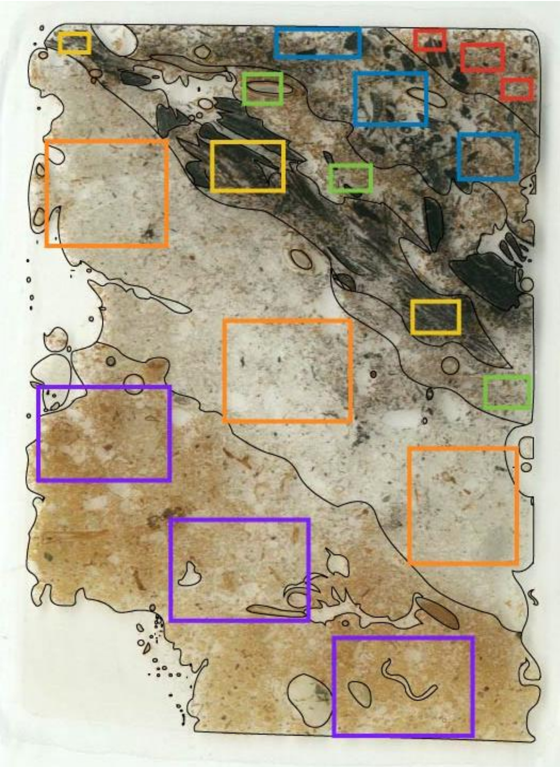


Figure 3.4: Annotated thin section slide showing the location of areas sampled on slide 2A, Lass mass Heden, using the SEM XRF; different colours used for the three sample points for each horizon

3.5 Analysis methodology

3.5.1 pH

The ph readings were tabulated and graphed using Microsoft Excel 2010 so that patterns for each site and cultural group could be seen so that differences between profiles, sites and between the two groups would emerge. The individual pH results for each site are discussed within the results section for each site, with comparisons being drawn in the discussion chapter.

3.5.2 Magnetic susceptibility

The mass specific magnetic susceptibility values were tabulated and graphed using Microsoft Excel 2010 so that any peaks within the mass specific magnetic susceptibility values calculated from the lab analysis could be seen. The individual results are discussed per site in the corresponding sub-sections of the Sámi and European landscape chapters, with comparisons being drawn in the discussion chapter; all readings and calculations listed in appendixes.

3.5.3 Micromorphology

The thin section slides described according to Stoops (2003) and Kemps guidelines (1985) with numerous sources of reference material and samples used to aid in the identification of each component; Reference materials included, but was not limited to, Courty *et al's* work on anthropogenic features (1989), Macphail *et al's* work on early agriculture (1990), Mallik and FitzPatricks work on burnt heathland (1996), Canti's work on spherulites (1997; 1999), and Simpson and Adderly's work on Multi-Room houses (2011), and reference material was obtained from the extensive collection at the University of Stirling, during micromorphology workshops at Tübingen and Pisa University (Germany and Italy respectively) and from Macphail's collection at the University College London (UK). An Olympus BX50 microscope was used for the identification and analysis of the thin section slides with an Olympus XC50 camera being used to capture images of key features. The slides were analysed under cross polarised, plane polarised and oblique incident light.

To aid with later comparisons the size and frequency of organic carbon and silt coatings, mineral grains and charcoal fragments has been recorded at increments from 1 – 6. The key tables below (figure 3.5) provide the conversion rates.

Organic carbon coating size:	Occurrence levels:	Silt coating size:
<10μm = 1	Very rare (trace) = 1	<250μm = 1
10-25μm = 2	Rare (trace -2%) = 2	250-500μm = 2
25-40μm = 3	Very few (2-5%) = 3	500-750μm = 3
40-60μm = 4	Few (5-15%) = 4	750-1000μm = 4
60-80μm = 5	Common (15-30%) = 5	1000-2000μm = 5
>80μm = 6	Frequent (30-50%) = 6	>2000μm = 6

Mineral grain size:	Mineral grain occurrence:	Charcoal size:
<500μm = 1	Very rare (trace) = 1	<250μm = 1
0.49 – 1mm = 2	Rare (trace -2%) = 2	250-500μm = 2
1.1 – 2.5mm = 3	Very few (2-5%) = 3	500-750μm = 3
2.6 – 5mm = 4	Few (5-15%) = 4	750-1000μm = 4
>5mm = 5	Common (15-30%) = 5	1000-2000μm = 5
		>2000μm = 6

Figure 3.5: Size conversion tables for micromorphology description tables

3.5.4 SEM

The output of elemental concentrations from the XRF analysis were collated and averaged in Microsoft Excel 2010. The data was then transferred to Minitab (version 16) where the normality of each stratum was checked using a General Linear Model with four in one residual plots showing the normal probability plot, the versus fits plot, a histogram of the data and the versus order plot. After discussing what was required from the data with the Senior Statistical Consultant, Kate Howie, at the University of Stirling, One Way Analysis of Variance* was chosen to check for statistically significant differences between the horizon types at, and between, each site, in addition to comparing the Sámi, European and control samples. As multiple comparisons were involved Tukey's multiple comparison was also used as it gave a clear output showing the differences between each set (site, horizon type or group). The full statistical outputs for all the ANOVA's, including Tukey's output, and the four in one graphs can be found in the appendix.

*One Way Analysis of Variance (1 Way ANOVA) is a statistical test which compares the means of two or more samples. In this instance the measurement variable is the chemical element and the nominal variable is the soil profile/horizon. The test assumes that samples are independent and normally distributed, that the variances of the populations are equal and that one factor is tested at a time.

Chapter 4: The Sámi landscape

4.1 Introduction

The Sámi landscape in this context is one which predates the settlement of Europeans and can typically be split between in-land winter settlements and coastal summer settlements which are connected by transit, herding and trade routes; a full history of this movement and the known and anticipated cultural activities at these sites have been explored in chapters 1 and 2.

Previous studies involving the Sámi culture have indicated that certain groups of the Sámi adapted their traditional lifestyles to incorporate European traits after prolonged contact with Europeans traders and/or settlers (Mathiesen *et al*, 1981). However literature searches considering what cultural indicators would remain from past Sámi activities returned studies which investigated anthropogenic activity within podzol soils. Although these soils are inherent in northern Sweden they concentrated on establishing if anthropogenic influence can change a podzols properties rather than which cultural indicators would be successfully retained within them; see Kristiansen 2000. As a result the main objectives of studying the Sámi sites of Prästsjödiket, Lass Mass Heden and Tjärdal are to identify what cultural indicators associated with Sámi occupation are retained within the inherent podzol soils and to use these to identify any impact traditional Sámi activities had on the landscape, however it is important to note that due to the low impact activities typical of the culture these may be indiscernible. Any impact on the landscape from traditional Sámi activities will provide new insights into the anthropogenic component of podzol soils i.e. how cultural information and indicators are retained within a podzolic environment. In order to achieve these aims a wide range of soils based analyse have been used. These will be discussed site by site throughout the chapter with the analysis considered from the field to the laboratory; all three Sámi site locations are shown in figure 4.1.

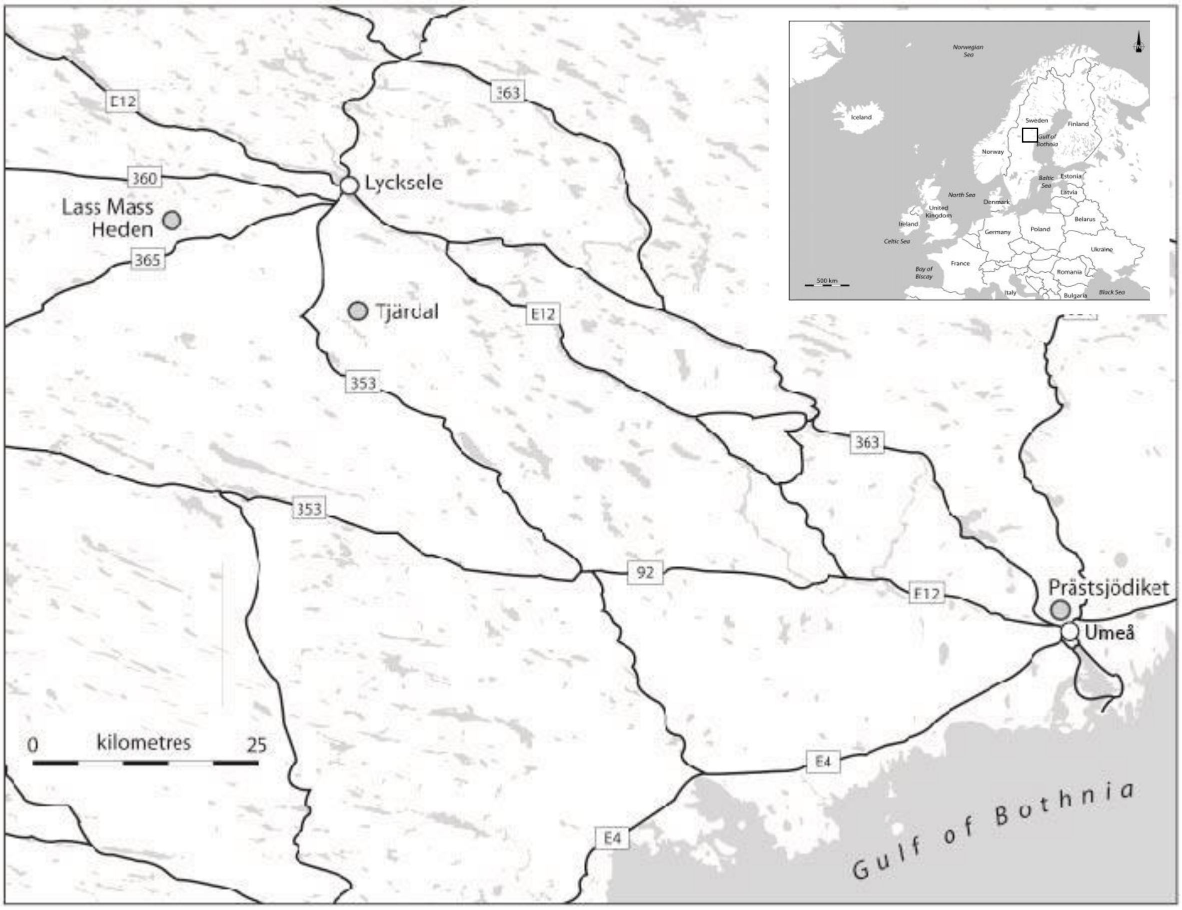


Figure 4.1: Map showing location of all three Sámi sites within Northern Sweden

4.2 Prästsjödiket

4.2.1 Background

Prästsjödiket is the only coastal Sámi site and is located near the city of Umeå in Västerbotten County. The site has been mapped as having a podzol soil and sedimentary bedrock (Swedish Geological Society 2010). Prästsjödiket has been previously excavated by Västerbotten museum which revealed fine objects such as a bronze dagger and burned human bones and teeth, dated to BC1590, which signified a burial site (Brander *et al* 2001). A range of cooking pits were also found and were dated between BC815-770 and AD665-775 suggesting that the site function changed to an occupation site on at least two separate occasions (Brander *et al* 2001). It has been proposed that the occupiers during the earlier term were of Sámi origin but due to signs of cultivation in the form of pollen analysis, from cores collected from the neighbouring Prästsjön Lake, during the second term of occupation the occupiers origins during the second period of settlement are unclear (Brander *et al* 2001).

4.2.2 Study locations

This site, which is now a hill, was described as an island around 500m from the mainland around BC1800-1500 by the archaeologists, when the sea level was 40m higher than present day, and was possibly used as a burial or religious site (Brander *et al*, 2001). However, as the sea level receded and the island became part of the mainland, it became inhabited again with cooking pits and hearths being located and excavated by local archaeologists (Brander *et al*, 2001). Radiocarbon dates obtained indicate that the site had been occupied intermittently with estimated occupation dates including from BC1750-1529, BC 815-770 and AD665-775 with the luminescence dating provided dates between AD800-1140 (Brander *et al*, 2001).

The occupants of the site is unknown as hearth stones indicate Sámi occupation but pollen analysis at the neighbouring Priest Lake indicates a period of cultivation; there was a decline in tree pollen and in increase in cereal pollen around BC500 (Brander *et al*, 2001) before tree pollen increased again at BC300, possibly indicating either abandonment of the land or a change in land-use, before decreasing again at AD300 (Brander *et al*, 2001); pollen core taken from Priests lake (Prästsjön), see figure 4.4 for location. The contemporary vegetation on the sites consists of pine forest with an underlying vegetation of heather, blaeberry bushes and moss/lichens.

The samples were taken from the open trenches left from the archaeological dig carried out by Brander, Joelsson, Löfqvist and Niemi, of Västerbotten museum, once the profile face had been cleaned up. The samples showed a change in soil type from organic, to gleyed, to a sandy soil showing the initial stages of podzolisation. The locations of the soil profiles have been mapped in figure 4.2 (in addition to a higher scale map showing the profiles in relation to the archaeology and an accompanying satellite image of the site in figures 4.3 and 4.4. respectively), a photograph of the typical area is shown in figure 4.5 and of an exposed soil profile in figure 4.6.

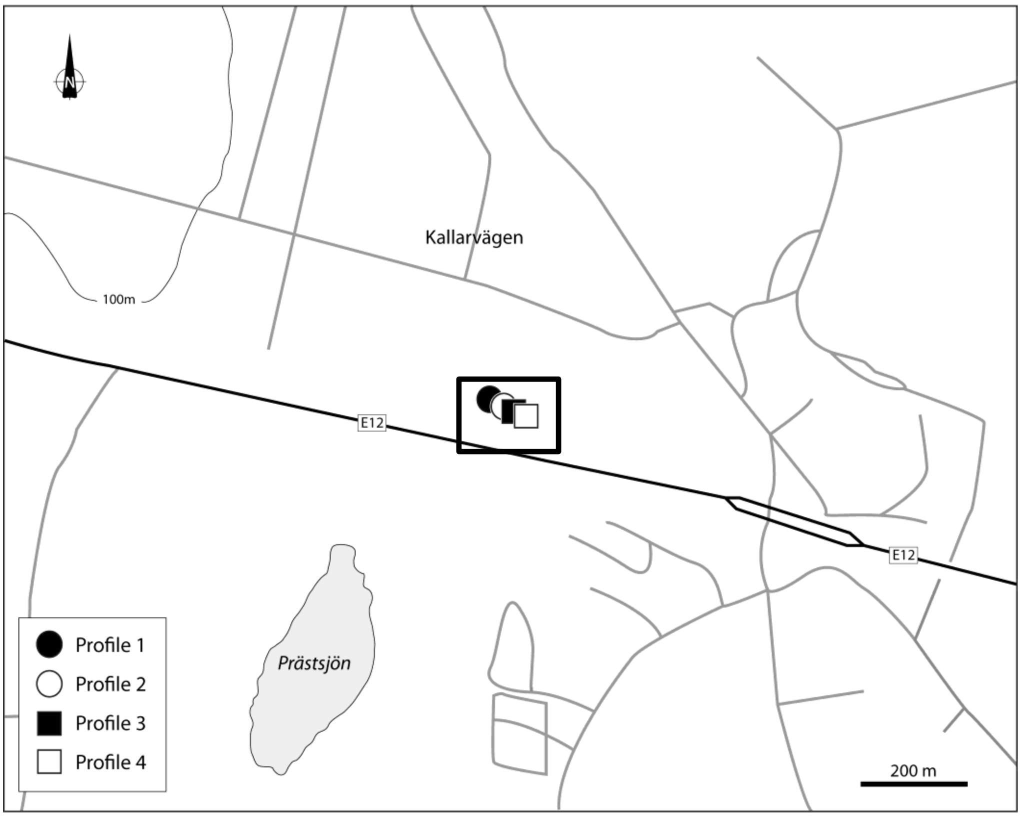


Figure 4.2: Map showing location of all profiles within the Prästsjödiket site

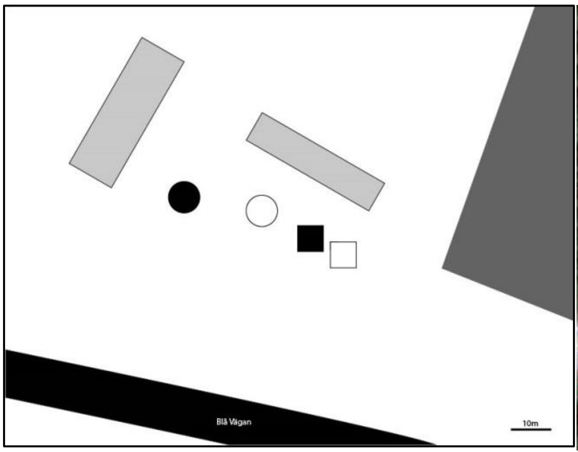


Figure 4.3: Map showing close up of Prästsjödiket as outlined in figure 4.2, with archaeology sites detailed in light grey and built up areas in dark grey; hearth stones no longer visible)

Figure 4.4: Screen grab of the Google satellite image showing profile locations (Google Maps, 2013)


Figure 4.5: Photograph of Prästsjödiket showing 'typical' view of site


Figure 4.6: Photograph of profile 4

Profile 1 had a very deep organic soil overlying clay. The top of the organic layer appeared to be beginning to dry out and was coarser in texture than the lower layers. There were roots throughout the whole organic layer as well as several pieces of wood; especially towards the bottom of the organic layer. There were also visible bands throughout the organic horizon that varied in colour; the dark bands could potentially represent periods of standstill. There are also some very dark bands at the lower end of the profile that could potentially be old land surfaces.

Profile 2 is a very wet gley and is overlain with a dark/wet organic horizon. There are two visible course grained sand bands midway down the gleyed horizon with mottles present above and below the sand bands; see figure 4.3 for photograph of profile with kubiena tins *in situ*.

Profile 3 is a podzol overlying well sorted glacial sands. Leaching is visible where the iron has moved down the profile and caused the redder tints in the middle. There is also a dark horizon at the top of the profile which is overlain with sand which could possibly indicate an old land surface.

A fourth profile was also dug 3m upslope from profile three and although the profile was shallower it showed a visibly more defined podzol. It also contained the darker horizon at the top of the profile but also contained a large pocket of charcoal within the E-horizon; possibly meaning that a hole has been dug before items were burnt.

4.2.3 Chronology

All charcoal samples were identified and weighed by S. Ramsay (2009, *pers communication*) before being prepared and dated using the AMS method at the NERC Radiocarbon Laboratory in East Kilbride, Scotland. All calibrated radiocarbon ages were calibrated using the University of Oxford Radiocarbon Accelerator Unit calibration programme (OxCal 4.1) and the IntCal 09 calibration curve.

Two samples were selected for dating from the Prästsjödiket site, both beetle fragments from profile 1, which returned calibrated dates of AD73-227 at a depth of 32cm and AD712-937 for a depth of 22cm; see figure 4.8 for a stratigraphic drawing showing the location of the charcoal samples within the profile, table 4.1 for the full sample information and figure 4.7 for the radiocarbon plot.

These dates are younger than the Bronze Age remains excavated on site but sample 1B overlaps the estimated date of a cooking pit on site which is believed to be Sámi in origin; cooking pit dated to AD665-775 (Brander *et al*, 2001: excavation report). As recent studies have shown beetle fragments to be reliable dating material (see Porch and Kershaw, 2010) and as it can be assumed that the beetles were living in the accumulating peat, any significant micromorphological and/or chemical results from this section can then be reliably attested to Sámi occupation.

Table 4.1: Table containing information on location, type and age of all radiocarbon dated material from Prästsjödiket

Site reference	Sample reference	Depth of sample (cm)	Lab codes	Material	Radiocarbon Age BP	Calibrated Date (≥95.4%)
Prästsjödiket	Sample 1B	22	38452 (GU26309)	Beetle fragment	1200±30	712-937AD
Prästsjödiket	Sample 1C	32	38453 (GU26310)	Beetle fragment	1870±30	73-227AD

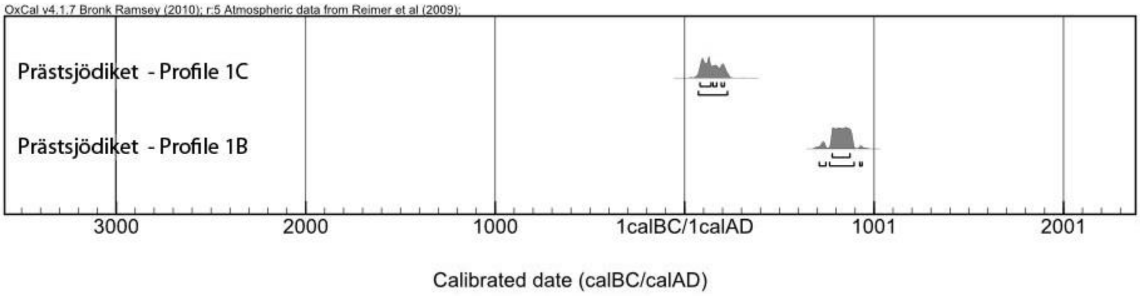


Figure 4.7: Radiocarbon plots showing the calibrated dates for the two samples dated from Prästsjödiket

4.2.4 Micromorphology

4.2.4.1 Profile 1

4.2.4.1.1 Description

Sample 1E was taken at a depth of 81cm from the adjoining wall (due to roots) and encompasses 4 organo-mineral micro-strata. The organic makeup of the micro-strata is very similar with the distinction occurring with the mineral content; see figure 4.8 for soil profile drawing and location of slide and table 4.2 for the micromorphology description tables. Starting at the bottom of the slide the lowest micro-stratum is mineral rich (34%) with well sorted quartz, feldspar and mica grains up to size band 2 with a trace of iron staining.

The overlying micro-stratum is more organic with only 5% mineral material. The mineral material is very fine (size 1) and well sorted with no iron staining. There is a trace of size 1 partially dissolved charcoal fragments, which occur in an extended linear pattern. There are also two organic, very dense, excremental micro-aggregates in the lower area of the micro-stratum.

The overlying, third, micro-stratum has an increased mineral content (35%), which was well sorted and accommodated as well as horizontal laminations of organic cell residue (15%). There was a trace of charcoal fragments (2 in total, size 1) within this stratum but they occur randomly. The upper organic accumulation was more organic rich (2% mineral material) and was again well sorted and accommodated.

This pattern of well sorted organo-mineral accumulations followed by organic accumulations continues in sample 1D, which was taken at a depth of 30cm and has 4 micro-strata starting with a mineral rich accumulation (34%) at the bottom of the slide followed by two organic accumulations, and another organo-mineral accumulation (30% mineral content).

Slide 1C was taken at a depth of 58cm and is a completely organic peat accumulation with evidence of limited biological activity (5% spheroidal excremental material).

Slide 1B was taken at a depth of 36cm and is a continuation of the organic peat accumulation seen in slide 1C. The groundmass varies in colour with a marked contrast between a dark brown in the centre of the slide followed by yellow and then another dark brown band in the upper fifth of the slide; the yellow and upper dark brown micro-strata are separated by a continuous band of tissue residue. The darker central area is a mixed charred and organic layer with the charcoal (5%) being embedded in the surrounding organic material; see figure 4.9 for photograph of charcoal and partially charred organic material. Sclerotia occur randomly throughout the slide (20 in total) but are concentrated in the charred area.

Slide 1A was taken at a depth of 10cm and is organo-mineral and very open (40% pore space) unlike the compact peat accumulations seen in slides 1C and 1B. This slide has obvious signs of disturbance including the inclusion of several peds of E-horizon material (see figure 4.10 for photograph) as well as further evidence of mixing, *in situ* charring and extensive biological reworking. The charred material includes two partially charred peds, which ranges from charcoal where the surface of the ped has been, through to un-charred organic material underneath (Simpson, *pers. Comm)*; see figures 4.11 and 4.12. The semicharred ped and the surrounding turf material have been disrupted and moved from their original position.

4.2.4.1.2 Interpretation

The preservation and size of the organic tissue, coupled with the presence of sclerotia, within the organic accumulations is indicative of a wet environment and peat formation. The variations in size, colour and preservation of the organic material in addition to the inclusion of several organo-mineral deposits throughout indicates multiple accumulations. The mineral accumulations, which are well sorted, accommodated and small in size, occur as several fine laminations, indicating that the material has been available intermittently. Due to the fine size and well sorted nature of the mineral material it could have been exposed through low level soil erosion and/or ground disturbance and deposited on-site through aeolian processes. However, the mineral material is sub-rounded which is indicative of water based wear, which combined with the emerging wet peat accumulations suggests that the material was deposited from low intensity flooding (the site was historically an island).

The two dense organic excremental micro-aggregates in the lower area of micro-stratum 1 are displaced from the surrounding material and due to their size ($2mm^2$), have been deposited by an unidentified burrowing macro fauna.

The traces of charcoal in slides D and E occurred in the organic micro-strata with no other anthropogenic indicators and for that reason, have been attributed to naturally induced forest fires rather than from anthropogenic burning activity; if they occurred within the alluvial organo-mineral deposits the charcoal could have originated upstream. The embedded nature of the charcoal in slide 1B indicates that the material was burnt *in situ*, with the limited volume and size indicating light burning of the surface vegetation. As there is no evidence of anthropogenic activity within this slide the burning has been deemed as naturally occurring.

Slide 1A presents the first clear indications of anthropogenic disturbance. Pockets of displaced E-horizon material, identified through the bleached nature of the mineral material, indicates physical disturbance to the upper soil profile, most likely from disturbance of neighbouring podzol soils. This disturbance coupled with the increased level of biological activity (15%) suggests that the profile is less water logged; as mixing aerates the profile.

The upper strata also contain charcoal, which includes a disrupted, partially charred ped. Interestingly however, the typical accumulation of organic material above a charring episode is not seen here. Looking at the high level of disturbance and the lack of organic material accumulation stimulated by a burning event, it has been assumed that the burning episode was anthropogenic in origin, namely for clearance purposes and/or to initiate the accumulation of organic material; the corresponding carbon dates indicate this disturbance occurred after the cooking pit was excavated by Västerbotten museum (see table 4.1. and figure 4.6 for dates).

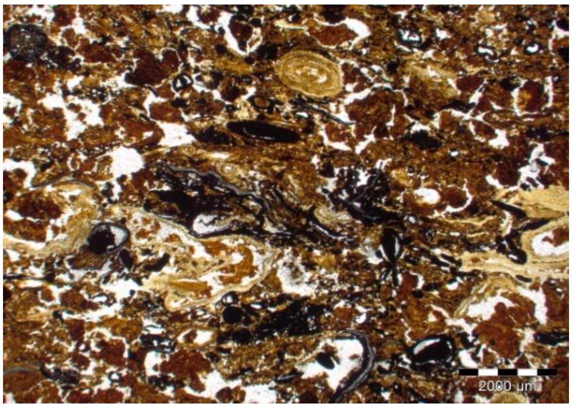


Figure 4.9: Charred stratum; mixed charcoal & OM, PPL x1.25

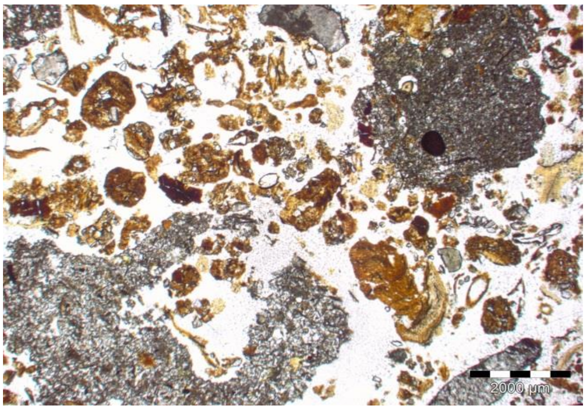


Figure 4.10: Displaced E horizon material ped, XPL x1.25 mag

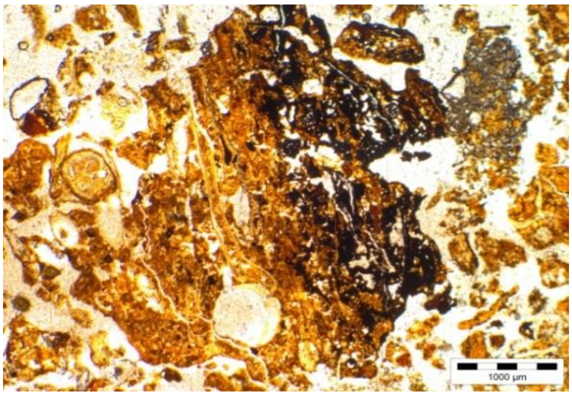


Figure 4.11: Partially charred ped, PPL x2 mag

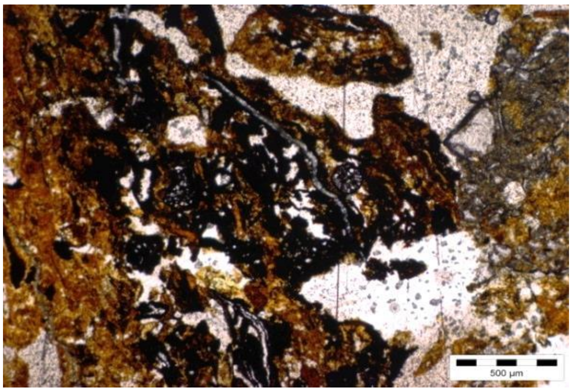


Figure 4.12: Charcoal within partially charred ped, PPL x4

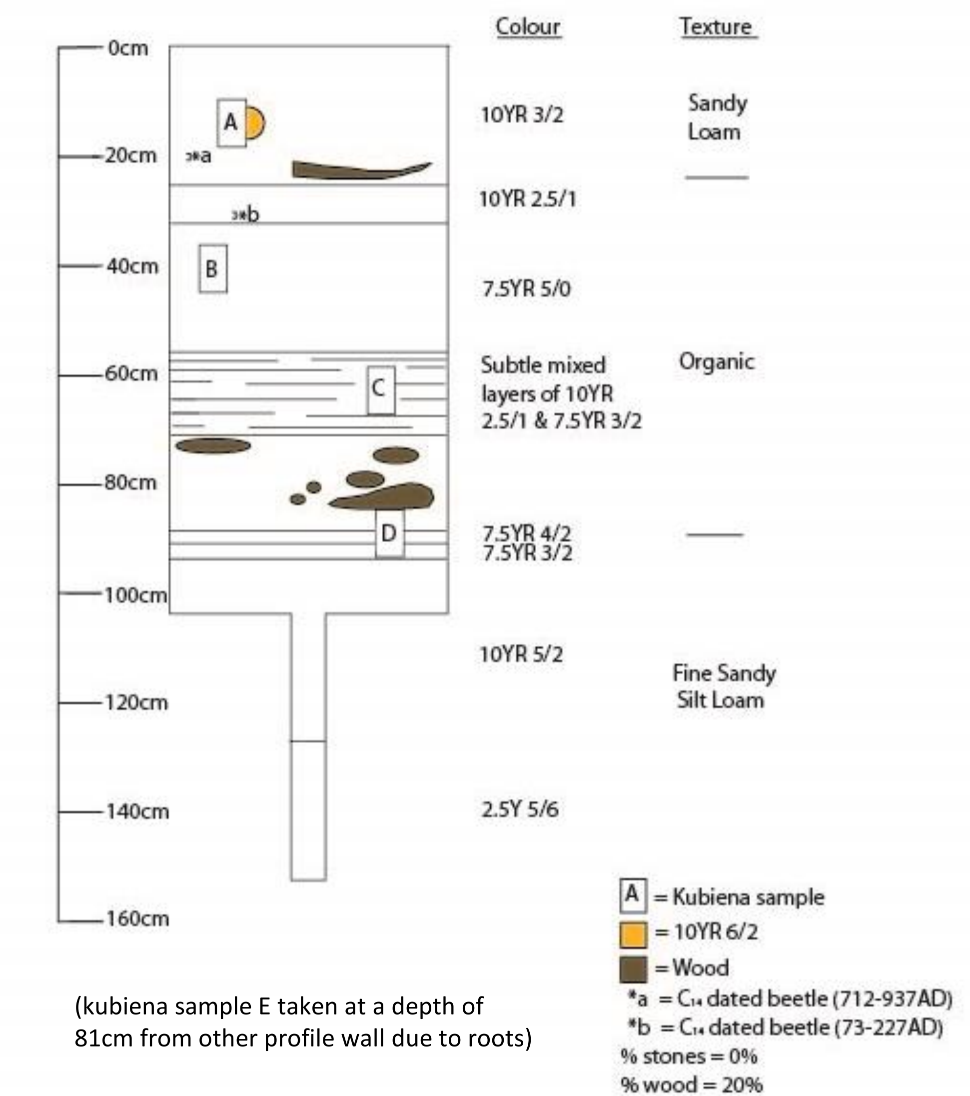


Figure 4.8: Photograph and soil profile diagram of profile 1

4.2.4.2 Profile 2

4.2.4.2.1 Description

Slide 2D was taken at a depth of 58cm and encompasses micro laminations of silt to medium sized sand grains with random fragments of organic material throughout (22%); see table 4.2 for the micromorphology description tables and figure 4.13 for soil profile diagram and photograph. The mineral material is well sorted and accommodated. The accumulations show visible signs of mottle formation and include sclerotia.

Slide 2C was taken at a depth of 45cm and is a continuation of the material seen in slide 2D. The central micro-stratum of fine grained clay material is the same as the material seen in slide 2D; size 3 organic carbon coatings are also common on the mineral grains in the first stratum from the movement of material down profile. The slide is also cut by a large root to the left of the slide.

Slide 2B was taken at 13cm and is another fine grained accumulation of clay sized material the same as slide 2D and is displaying mottling but also a lenticular microstructure.

Slide 2A was taken at a depth of 6cm and encompasses 4 micro-strata, which starting from the bottom are an E-horizon, charred stratum and two organic strata. The E-horizon is poorly formed as it is partially iron stained (10%), has 2% charcoal (fragmented and partially dissolved) and is rich in organic material (50%); particularly fine organic A-horizon type material (45%). The overlying charred strata shows evidence of movement down the profile; see figures 4.14 and 4.15 for photograph showing linear separation of charcoal fragments.

The charred strata are directly overlain by an organic accumulation of peat type material. The organic material shows moderate biological activity with an input of fine sand (5%). This is then overlain by a secondary organic accumulation, which has a much higher mineral input (20%) and is larger in size; size band 2 rather than band 1 seen in lower organic strata. This strata is still biologically active but also includes randomly located charcoal fragments (2%).

4.2.4.2.2 Interpretation

Overall, this profile appears to be a natural gley, evident through the formation of mottles, which is subject to podzolisation processes, evident through eluviation processes. The size and well sorted/accommodated nature of the fine grained mineral deposit indicates that the material is fluvio-glacial in origin. The variations in size indicate that the intensity of the flooding varied but was always low, with the inclusion of sclerotia further evidencing a waterlogged environment.

An E-horizon had begun to develop at the top of the gley which is evident through its bleached, iron and organic depleted nature. The movement of the fine grained materials down profile from this process is responsible for the micro-stratums of clay material in slide 2C. The large root within this slide indicates that the profile has not always been waterlogged at this depth, perhaps indicating either a seasonal flooding event or, it is related to the isostatic rebound of the area which has resulted in dropping sea levels. The inclusion of a high percentage of the organic material within the E-horizon is a result of the eluviation of organic material from the original overlying A-horizon.

The lenticular microstructure present is evidence of frost action near the surface. A lenticular microstructure has been visible in frost heaved soils across all sites and has been identified as an indicator of frost action; it is formed through the expansion and compaction of the soil freezing and thawing which forms lenticular voids and exaggerates linear accumulations of fine material.

The A-horizon has experienced a burning event, with some of the charred and un-charred organic materials having percolated down into the E-horizon. It is worth noting that on first inspection the intact charred material/strata appeared to be a past land surface, but after careful comparison with control samples this was rejected and linked to the undisturbed nature of the profiles. The movement of the organic material from the charred past A-horizon has not affected the accumulation of organic material above the stratum, which accumulated alongside windblown sand; sand indicated as aeolian in nature due to its fine size. The input of wind-blown sand then increased in both size and quantity leading to the upper organic stratum being more mineral rich than the lower (20% compared to 5%). Windblown charcoal material has also accumulated along with the mineral and organic materials in the upper stratum and indicates that there has been continued light burning activity near the profile after the burning event; which has increased in intensity over time. However, as there is no evidence to support the charring episode as being anthropogenic in origin, it has been declared as natural; although the traces of micro-charcoal and fine mineral material in the upper organic accumulation is indicative of light anthropogenic disturbance nearby there is no evidence of direct use of this profile.

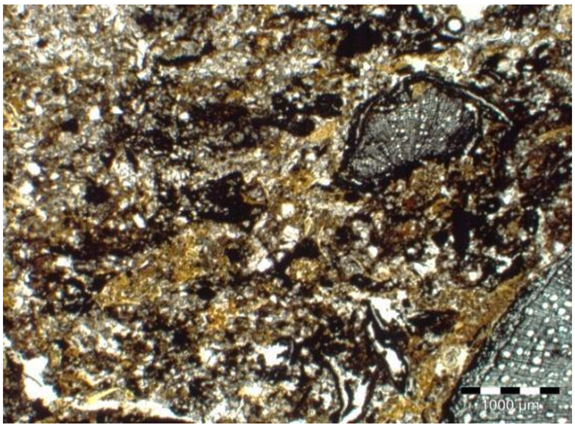


Figure 4.14: Linear separation of charcoal, PPL x2

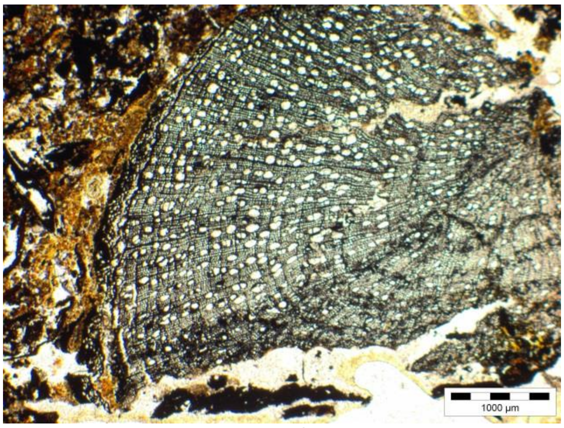


Figure 4.15: Linear separation of charcoal, PPL x2 mag

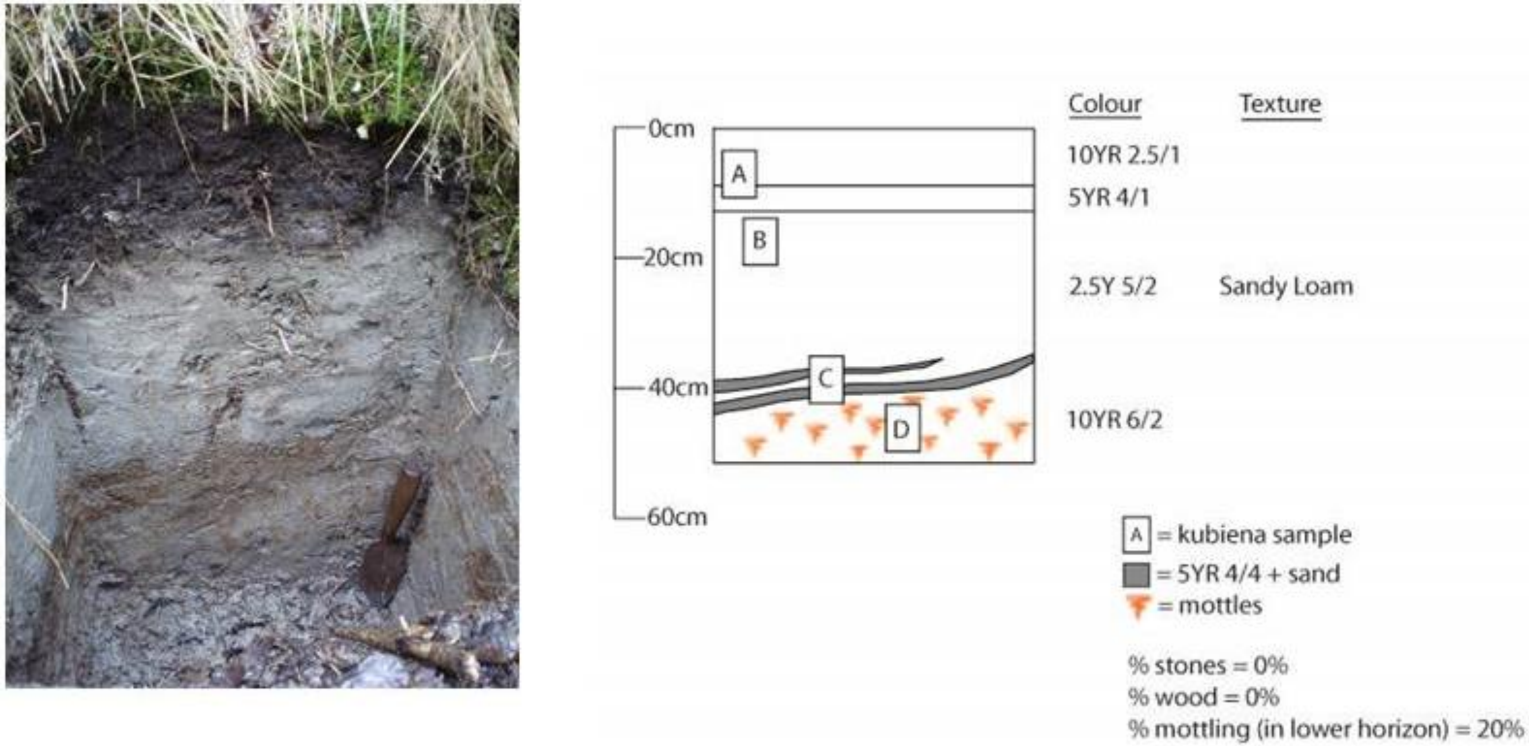


Figure 4.13: Photograph and soil profile diagram of profile 2

4.2.4.3 Profile 3

4.2.4.3.1 Description

Slide 3D was taken at a depth of 50cm and slide 3C at a depth of 27cm, both are coarse grained sands with the mineral grains decreasing in size from size band 4 in slide 3D to size band 3 in 3C as expected with decreasing depth; see figure 4.16 for soil profile drawing and location of slide and table 4.2 for the micromorphology description tables.

Slide 3B was captured at a depth of 5cm and encompasses 3 micro-strata which starting from the bottom are an E-horizon, charred stratum and organic A-horizon. The E-horizon is poorly developed with iron staining on 5% of the mineral material, limited root material (trace) and movement of fine organic material and charcoal fragments from the overlying charred stratum.

The overlying charred stratum has several discreet charcoal laminations. The charred material is overlain with a mix of fine organo-mineral material and coarse grained minerals (size 2). The organic accumulation contains two further mineral accumulations of coarse grained material which occurs in continuous bands which are on average 5mm deep, as well as 'very few' size 2 organic carbon coatings.

Slide 3A was taken at a depth of 3cm and encompasses 5 micro-strata, which from bottom to top are the E-horizon, charred stratum and organic accumulation seen in slide 3B as well as an additional two overlying organic strata. The stratum has the same characteristics as seen in slide 3B, as it is a continuation of the same material, with the same movement of fine organo-mineral material and charcoal fragments down profile as well as the inclusion of two large ($10mm^2$) root cavities; one backfilled (see figures 4.17 and 4.18 for photographs). This slide was taken to the right of slide 3B, see figure 4.16 for profile drawing. The charcoal was visibly thinner than in the corresponding stratum in slide 3B which is reflected in its thin and intermittent charcoal stratum. The charcoal ranges in form from fragments (10%) to dissolved amorphous black material (20%), which although comparable percentage-wise to the charcoal stratum recorded in slide 3B, is far thinner in appearance (1mm wide in 3A compared to 5mm wide in slide 3B) with their being less charcoal present overall. As was seen in slide 3B, an organic accumulation has formed above the charred stratum with the intermittent mineral accumulations seen in the form of strata 3 and 1; a single charcoal fragment in stratum 1 (size 2) strengthens the argument of disturbance. Due to this sample being taken further up the profile considerably more of the organic material was captured than in slide 3B, which allows the fine micro laminations of root and tissue residue and traces of biological activity to be seen more clearly. Organic carbon coatings are visible on the mineral grains throughout these layers and decrease in size but increase in number over time with size 3 accumulations being very rare in stratum 3 (directly overlying the charred stratum) and size 2 accumulations being common in the upper two organic strata.

4.2.4.3.2 Interpretation

Overall, this has been a natural sand accumulation with the initial stages of E-horizon formation and charring of the original A-horizon. The only disturbance seen has been linked to the large roots present in the profile, as identified from Kooistra and Pulleman (2010); the burning episodes have been deemed natural in origin due to the lack of anthropogenic activity.

Due to the depth and size of both the charcoal fragments and the intermingled mineral material within the discreet charcoal laminations in slide 3B, it has been surmised that there has been two burning events and that the remaining thin laminations are from movement of the material from illuviation processes; material in lower charred stratum too large to be translocated. The lower charcoal band is incomplete, indicating a low intensity burning of surface vegetation. The charred material is overlain with an organic accumulation, indicating that the burning episode did encourage the accumulation of organic material but that local disturbance covered up this accumulation; on average 8mm between the two charred strata. Size 2 organic carbon coatings are visible on a ‘few’ of the mineral grains (see figure 3.5 for size conversion key). The secondary burning episode is another low intensity charring of the surface vegetation, which led to an organic accumulation with a trace of fine grained (silt) mineral grains indicating that the disturbance responsible for covering the original charring episode has ceased. The occurrence of multiple organic and mineral accumulations since the first burning episode indicates intermittent occupation and/or disturbance near the profile.

The thicker charcoal and mineral accumulations in slide 3B compared to 3A indicate that the intensity of the fire was greater to the left of the profile; this may be related to the origin of the fire or small changes in local topography and vegetation cover during these episodes. The second burning episode seen in slide 3B is also visible in slide 3A, which led to sustained organic accumulation in both slides. The continuous, undisturbed laminations of organic material visible in slide 3A indicate that there has been no direct amendment to the soil, with the mineral accumulations acting as evidence of disturbance elsewhere. The thinning of the charcoal stratum from left to right in slide 3A indicates that the burning was most intense to the left of this profile.

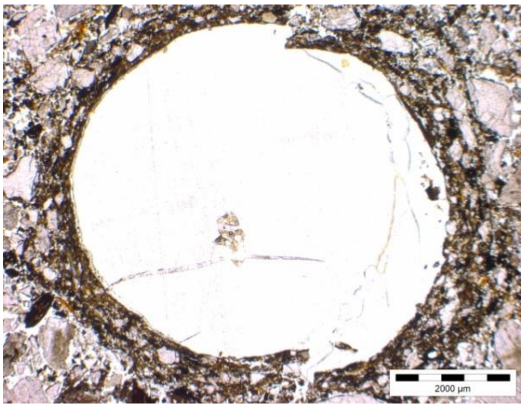


Figure 4.17: Large root cavity burrow, PPL x1.25 mag

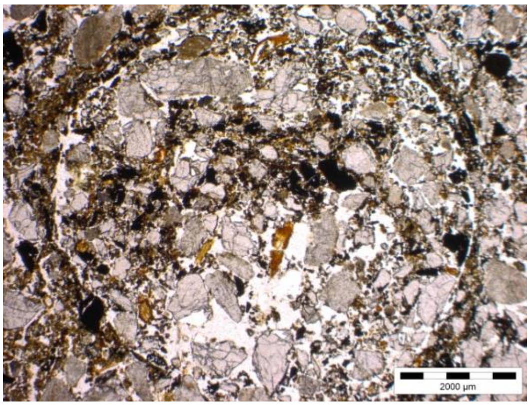


Figure 4.18: In-filled root cavity, XPL x1.25 mag

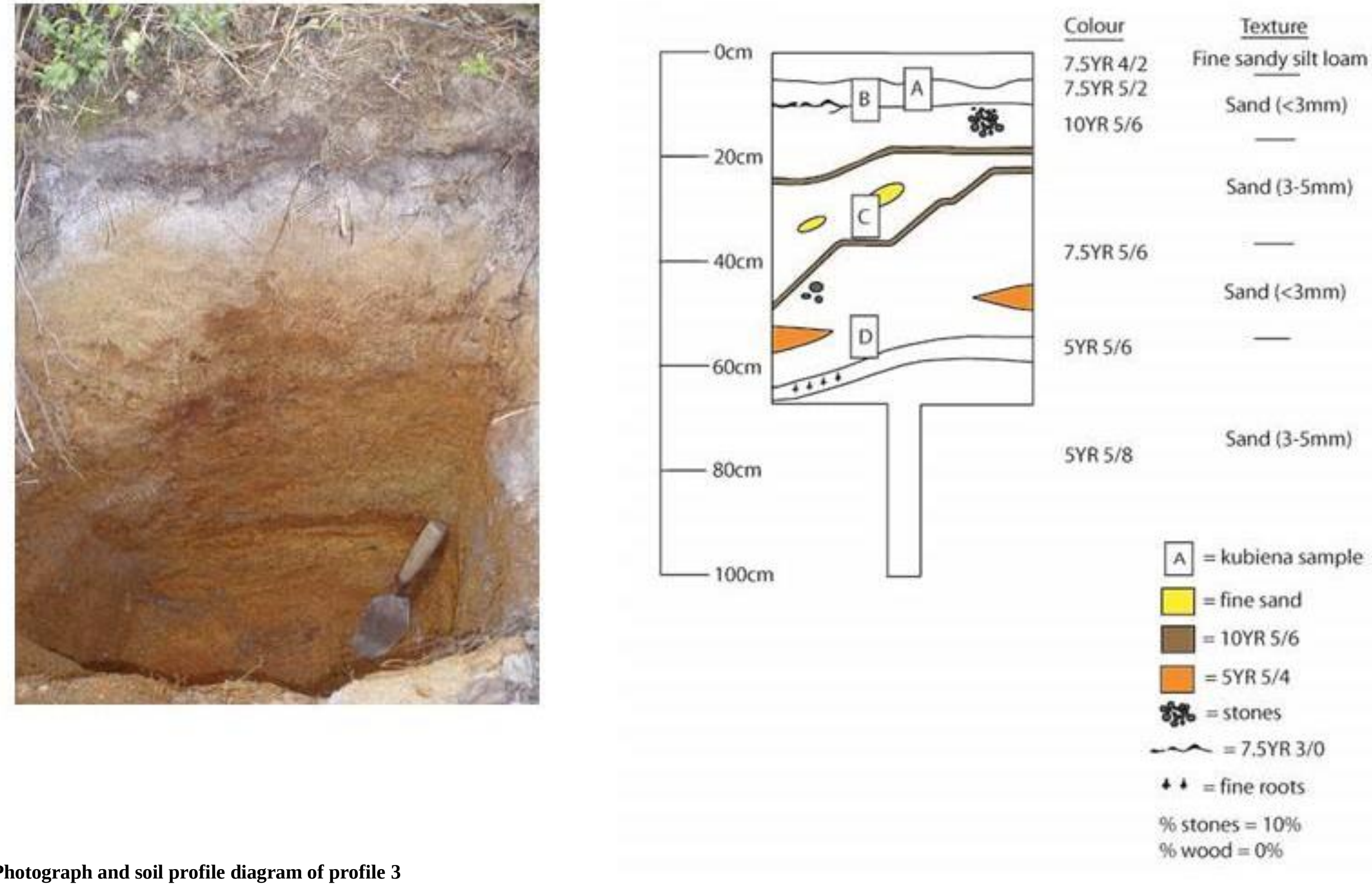


Figure 4.16: Photograph and soil profile diagram of profile 3

4.2.4.4 Summary

Overall, this site has formed on fluvio-glacial deposits, which have developed into peat, gleys or podzols and all have experienced at least one burning episode. All profiles, including the peat, were charred, indicating blanket burning across the area. The exaggerated movement of organic material down profile, in all three profiles, fits with the natural podsolization processes but has been heightened by the higher level of percolation and drainage. This is from the earlier intermittent flooding periods (profile 2) and increased precipitation and/or over-ground flow teamed with the freely draining sand deposits that the soils overlie; the flooding and waterlogging has been intermittent as several layers of varying grain size accumulations can be seen in profile 2 as well as gleying and root growth within the same stratum.

The site is natural but with evidence of several light disturbance episodes with fine mineral accumulations being evident in all three of the profiles; the wind-blown charcoal visible in the upper layers of profile 2 may have originated from the same source as the charcoal fragment in the upper stratum of profile 3. The radiocarbon dates indicate that the disturbance visible in sample A, profile 1, occur after the cooking pit identified by Västerbotten museum was in use. However as the site has been used intermittently it is possible that the disturbance was caused by the same group at a later period (Sámi returned to same settlement sites) and that the corresponding cooking pit(s) was not identified/sampled.

Table 4.2: Thin section micromorphology descriptions for Prästsjödiket

				Coarse mineral material (>10µm)														Coarse Organic material (>10µm)								Fine Organic Material (<10µm)				Pedofeatures				Structure			
Profile	Micro-strata	Depth (cm)	Quartz %	Quartz maximum size	Feldspar %	Feldspar maximum size	Siltstone %	Siltstone maximum size	Mica %	Mica maximum size	Glauconite %	Arrangement of minerals	Fine mineral material (<60µm)	Silt coating frequency	Silt coating maximum size	Organic carbon coatings frequency	Organic carbon coating maximum	Organ residue	Tissue residue	Largest tissue residue (mm)	Lignified tissue	Sclerotia	% Charcoal	Largest charcoal	Cell residue	Amorphous black	Amorphous yellow	Amorphous brown	Amorphous red	Excremental (*Spheroidal*) 50-100µm	Fe impregnated mineral material %	Fe impregnated organic material %	% void space	Microstructure	Course material arrangement	Groundmass b fabric	C/F ratio
1A	A	10	5	3	t	1	t	1	t	1	-	SA	Grey with low order IC	-	-	-	-	5	15	100 x 50	-	2	t	2	20	t	5	5	-	15	-	10	40	V-weak pedality, crumb	Unsorted & un-accommodated	Double spaced enaulic. Brown SS	2/1
1B	O	36	t	1	-	-	-	-	-	-	-	-	Grey with low order IC	-	-	-	-	t	10	250 x 30	t	20	5	3	10	t	10	25	5	15	-	10	20	V weak pedality. Granular	Partially sorted & accommodated	Close porphyric, un-differentiated B-fabric	3/1
1C	0	58	-	-	-	-	-	-	-	-	-	-	N/A	-	-	-	-	10	5	120 x 50	2	-	-	-	15	2	15	20	5	5	-	-	20	Moderate planer microstructure	Partially sorted, well accommodated	Close porphyric, undifferentiated B-fabric	1/1
1D	B/1	83	30	1	-	-	-	-	-	-	-	SR	Grey + low order IC	-	-	-	-	2	10	50 x 10	-	-	-	-	10	t	20	5	5	-	-	5	20	Moderate developed, granular	Well sorted & accommodated	Close fine enaulic. Grey SS	1/1
	O/2		5	1	-	-	-	-	-	-	-	SR	Clear + low order IC	-	-	-	-	5	15	30 x 70	-	-	-	-	15	t	20	20	5	-	-	t	10	Moderate developed, granular	Well sorted & accommodated	Close fine enaulic. Orange brown SS	1/1
	O/3		5	1	-	-	-	-	-	-	-	SA	Clear + low order IC	-	-	-	-	5	20	100 x 350	-	-	-	-	10	5	20	10	5	-	-	t	10	Weak pedality. Planer MS	Well sorted & accommodated	Close fine enaulic. Org brown SS	1/2
	B/4		30	1	2	1	t	1	2	1	-	SR	Clear + low order IC	-	-	-	-	5	10	20 x 200	-	1	t	1	10	5	10	10	5		5	10	5	Weak pedality. Crumb.	Well sorted & accommodated	Close fine enaulic. Grey SS	1/1

				Coarse mineral material (>10µm)														Coarse Organic material (>10µm)								Fine Organic Material (<10µm)				Pedofeatures				Structure			
Profile	Micro-strata	Depth (cm)	Quartz %	Quartz maximum size	Feldspar %	Feldspar maximum size	Siltstone %	Siltstone maximum size	Mica %	Mica maximum size	Glauconite %	Arrangement of minerals	Fine mineral material (<60µm)	Silt coating frequency	Silt coating maximum size	Organic carbon coatings frequency	Organic carbon coating maximum	Organ residue	Tissue residue	Largest tissue residue (mm)	Lignified tissue	Sclerotia	% Charcoal	Largest charcoal	Cell residue	Amorphous black	Amorphous yellow	Amorphous brown	Amorphous red	Excremental (*Spheroidal*) 50-100µm	Fe impregnated mineral material %	Fe impregnated organic material %	% void space	Microstructure	Course material arrangement	Groundmass b fabric	C/F ratio
1E	1	81	2	1	-	-	-	-	-	-	-	SA	Clear + low order IC	-	-	-	-	t	20	80 x 50	-	-	-	-	10	2	20	20	5	-	-	-	20	Moderate pedality. Granular.	Well sorted & accommodated	Close fine enaulic. Orangey brown SS	1/2
	2		30	2	5	1	-	-	t	1	-	SR	Clear + low order IC	-	-	-	-	-	4	40 x 10	-	-	t	1	15	t	10	10	5	-	-	-	20	Weak pedality. Granular.	Well sorted & accommodated	Close fine enaulic. Orangey brown SS	1/3
	3		5	-	-	-	-	-	-	-	-	SR	Clear + low order IC	-	-	-	-	5	10	12 x5	-	-	-	-	10	t	10	10	5	-	-	-	40	Weak pedality. Granular.	Well sorted accommodated	Close fine enaulic. Orage brown SS	1/3
	4		30	2	2	1	-	-	2	2	t	SA	Clear + low order IC	-	-	-	-	5	10	12 x5	-	-	-	-	10	t	10	10	t	-	t	-	10	Weak pedality, channel	Well sorted accommodated	Close fine enaulic. Ornge brown SS	1/2
2A	1/A	6	20	2	5	2	5	2	t	1	-	SR	Clear + low order IC	-	-	-	-	-	5	225 x 50	t	-	2	2	10	5	10	15	5	t	t	10	20	Moderate pedality, sub-angular blocky	Well sorted, partially accommodated	Single spaced porphyric. Orangey brown SS	1/2
	2/O		5	1	-	-	-	-	-	-	-	SA	Clear + low order IC	-	-	-	-	-	t	25 x 25	-	-	-	-	10	5	20	30	t	t	-	10	20	Moderate pedality, planer	Well sorted, partially accommodated	Open porphyric orangey brown SS	2/1
	3/O		10	1	-	-	-	-	t	1	-	SA	Clear + low order IC	-	-	-	-	-	-	-	-	-	20	6	10	10	10	10	5	-	-	10	25	Weak pedality, granular	Well sorted, partially accommodated	Single spaced porphyric, brown SS	2/1
	4/E		35	2	2	1	t	2	t	1	-	SA	Clear + high order IC	-	-	-	-	t	5	50 x 175	-	-	t	2	10	10	5	5	t	-	t	10	15	Weak pedality, granular	Well sorted, partially accommodated	Single spaced porphyric, brown SS	1/1

				Coarse mineral material (>10µm)														Coarse Organic material (>10µm)								Fine Organic Material (<10µm)				Pedofeatures				Structure			
Profile	Micro-strata	Depth (cm)	Quartz %	Quartz maximum size	Feldspar %	Feldspar maximum size	Siltstone %	Siltstone maximum size	Mica %	Mica maximum size	Glauconite %	Arrangement of minerals	Fine mineral material (<60µm)	Silt coating frequency	Silt coating maximum size	Organic carbon coatings frequency	Organic carbon coating maximum	Organ residue	Tissue residue	Largest tissue residue (mm)	Lignified tissue	Sclerotia	% Charcoal	Largest charcoal	Cell residue	Amorphous black	Amorphous yellow	Amorphous brown	Amorphous red	Excremental (*Spheroidal*) 50-100µm	Fe impregnated mineral material %	Fe impregnated organic material %	% void space	Microstructure	Course material arrangement	Groundmass b fabric	C/F ratio
2B	E	13	35	3	20	2	10	1	15	1	t	SR	Clear + low order IC	-	-	-	-	2	t	50 x 100	-	-	-	-	-	t	t	t	-	-	-	-	20	Weak pedality, lenticular	Well sorted & accommodated	Coarse monic grey SS	5/1
2C	E/1		45	25	2	15	2	10	2	2	t	SR	Clear + low order IC	-	-	3	4	-	t	450 x 100	-	-	-	-	15	t	2	t	t	-	t	5	30	No pedality, single grain microstructure	Very well sorted, un-accommodated	Coarse monic grey SS	5/1
	E/2		40	2	15	1	5	1	25	1	-	SR	Clear + low order IC	-	-	-	-	-	-	-	-	-	-	-	t	-	-	-	-	-	t	-	10	No pedality, single grain microstructure	Very well sorted & accommodated	Fine monic, grey SS	1/5
2D	E	58	35	-	5	-	t	-	20	-	-	SR	Clear + low order IC	-	-	-	-	-	5	100 x 50	5	1	-	-	5	t	5	t	2	-	t	t	15	No pedality, single grain microstructure	Well sorted & accommodated	Coarse to fine monic, grey SS	1/5
3A	1	3	30	3	15	3	5	2	t	1	t	SR	Grey / low order IC	-	-	2	4	5	t	100 x 50	-	-	2	3	t	t	5	10	-	-	5	-	30	Very weak pedality, granular	Un-sorted + accommodated	Fine enaulic, orangey brown SS	2/1
	2	1	2	1	-	-	-	-	-	-	-	SR	Grey / low order IC	-	-	2	4	20	10	200 x 50	t	-	-	-	10	t	5	20	-	t	-	t	20	Very weak pedality, granular	Partially sorted & un-accommodated	Single spaced enaulic. Orangey brown SS	1/2
	3	2	10	2	5	2	t	2	t	1	-	SR	Grey / low order IC	-	-	3	1	5	10	25 x 25	-	-	t	1	10	t	5	15	t	t	-	-	25	Very weak pedality, granular	Partially sorted & un-accommodated	Single spaced enaulic. Orangey brown SS	2/1

				Coarse mineral material (>10µm)														Coarse Organic material (>10µm)								Fine Organic Material (<10µm)				Pedofeatures				Structure			
Profile	Micro-strata	Depth (cm)	Quartz %	Quartz maximum size	Feldspar %	Feldspar maximum size	Siltstone %	Siltstone maximum size	Mica %	Mica maximum size	Glauconite %	Arrangement of minerals	Fine mineral material (<60µm)	Silt coating frequency	Silt coating maximum size	Organic carbon coatings frequency	Organic carbon coating maximum	Organ residue	Tissue residue	Largest tissue residue (mm)	Lignified tissue	Sclerotia	% Charcoal	Largest charcoal	Cell residue	Amorphous black	Amorphous yellow	Amorphous brown	Amorphous red	Excremental (*Spheroidal*) 50-100µm	Fe impregnated mineral material %	Fe impregnated organic material %	% void space	Microstructure	Course material arrangement	Groundmass b fabric	C/F ratio
	4		20	2	10	2	t	2	2	1	-	SR	Grey + high order IC	-	-	-	-	5	5	100 x 25	t	-	10	3	5	20	t	5	-	-	-	t	20	Weak pedality, crumb	Un-accommodated, partially sorted	Close enaulic, grey SS	2/1
	5		20	3	10	2	t	2	2	1	-	SR	Grey + low order IC	-	-	-	-	2	5	150 x 50	-	-	2	1	5	5	t	2	t	t	t	t	40	Weak pedality, crumb	Un-accommodated, partially sorted	Close enaulic, grey SS	3/1
3B	1	5	5	2	2	1	2	2	t	1	-	SA	Grey + low order IC	-	-	-	-	5	10	100 x 50	-	-	t	1	5	2	5	10	-	-	5	10	40	Moderate pedality, sub-angular blocky	Partially sorted & accommodated	Close enaulic, grey SS	1/3
	2		20	2	10	2	5	1	t	1	-	SA	Grey + low order IC	-	-	-	-	t	t	100 x 12.5	-	-	15	5	5	10	t	5	t	-	5	10	30	Weak pedality, granular	Un-sorted, un-accommodated	Single spaced enaulic, brown SS	2/1
	3		20	2	20	2	5	2	2	1	-	SA	Grey + low order IC	-	-	-	-	t	t	50 x 50	-	-	t	1	2	2	5	5	t	-	5	5	30	No pedality, single grain MS	Un-sorted, un-accommodated	Convex gefuric, brown SS	5/1
3C	C	27	20	3	10	3	15	3	5	1	t	SA	Grey + high order IC	-	-	-	-	t	-	-	-	-	-	-	2	t	t	t	-	-	20	t	50	No pedality, single grain MS	Well sorted, un-accommodated	Convex gefuric, brown SS	5/1
3D	C	50	20	4	15	4	15	4	2	1	t	SA	Grey + low order IC	-	-	-	-	-	-	-	-	-	-	-	-	t	t	t	-	-	25	-	50	No pedality, single grain MS	Well sorted, un-accommodated	Convex gefuric, brown SS	6/1

4.2.5 Chemical analysis

4.2.5.1 pH

The pH values have been calculated from the bulk soil samples collected and graphed in figure 4.15. They show that in profile 1, the organic peat, that the pH is slightly higher within the topsoil (sample 1A) with little variation throughout the profile; overall the profile is very acidic with a pH value of between 2.5 to 3.5 throughout. Profile 2, the gley, shows an increase in acidity with depth from just over 4.6 to 3.8 whereas, the developing podzol in profile 3 shows the reverse with the pH reducing in acidity with depth from 4.8 to 5.1 (see figure 4.19). The differences in the acidity level and trends with depth can be related to the differing soil types.

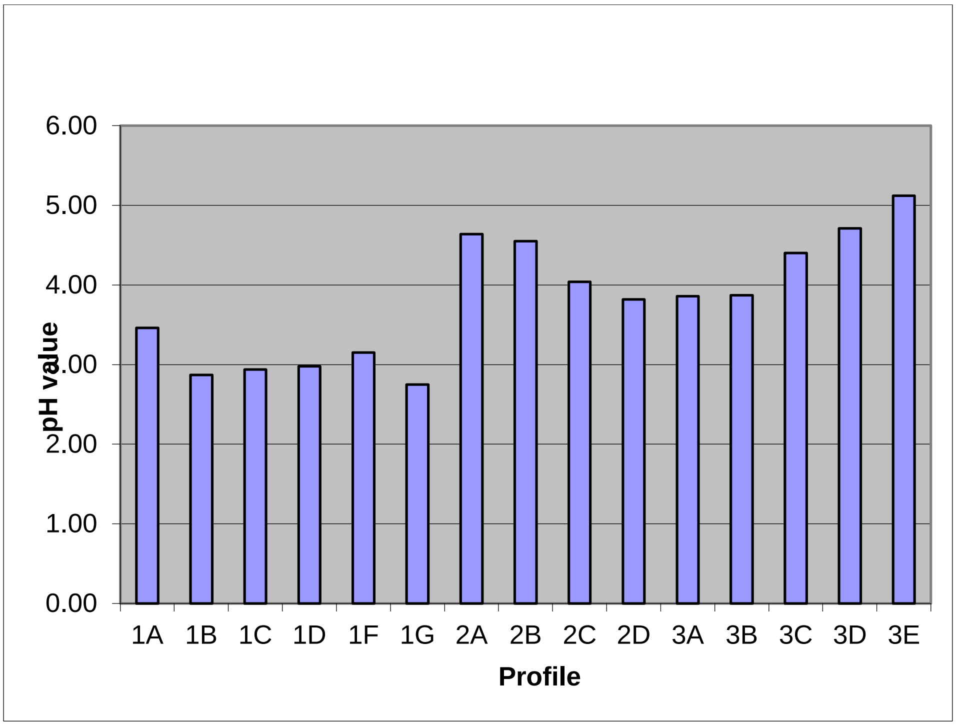


Figure 4.19: pH values for all profiles at Prästsjödiket

4.2.5.2 Magnetic susceptibility

The mass specific magnetic susceptibility was calculated for each bulk soil sample collected and is graphed in figure 4.20. Due to the differing nature of the three profiles they cannot be compared to establish differences in the immediate area however the peaks in profile 3, samples A and D, are of interest and indicate burning activity; micromorphological analysis of the corresponding samples links the peaks to inclusions of charred organic material confirming burning activity.

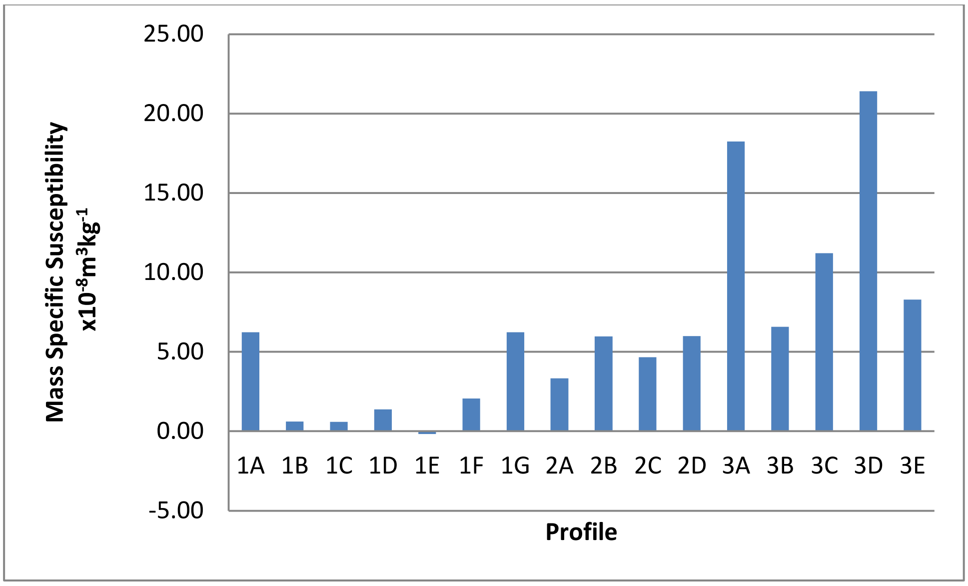


Figure 4.20: Mass Specific Magnetic Susceptibility values for Prästsjödiket

4.2.5.3 SEM analysis

A scanning Electron Microscope (SEM) was used to chemically measure each micro-stratum, as identified by micromorphological analysis, within the thin section slides with these micro-strata being categorized and compiled according to soil horizon, before being statistically analysed for a suite of elements; sodium, magnesium, aluminium, potassium, phosphorous, calcium, titanium, iron, chloride, manganese, sulphur and nickel were tested. The normality of the data was checked by completion of a General Linear Model with accompanying four in one residual plot; showing the normal probability plot, versus fits, histogram and versus order graphs (see appendixes). One way analysis of variance (ANOVA) tests were then carried out on the data to determine any significant relationships. There were, however, no statistically significant relationship between Prästsjödiket and the other Sámi sites for any of the elements analysed; the full list of outputs from the ANOVA's can be found in the appendixes.

4.2.6 Summary

A pattern of thin burnt horizons directly overlying the current E-horizon and being overlain by an often very biologically active organic accumulation indicates that the localised changes within the soil from the burning event (i.e. chemical) is enough to alter the soil forming properties resulting in the accumulation of organic material; several profiles show secondary burning events and subsequent organic accumulations. Fine fragments of possible past A horizon material and the size of the charcoal fragments indicate that the burning was typically of the surface vegetation and shallow A horizon. However it is possible that the A horizon was not always so shallow and that the changes discussed in the podzol model in chapter 2 not only resulted in the accumulation of organic material above the charred material but that it also initiated and/or accelerated the formation of the podzols albic horizon resulting in the charred material appearing to directly overlie to the current albic E horizon at present. The relevance of this within this section is the impact that the albic horizon has had on the charred material moving down profile from the charred horizon. In several cases the charred material has begun to transform into a partially dissolved fragment which has lost some, if not all, of its typical structure. This alteration has been attributed to the acidic environment of the albic horizon and indicates that other cultural indicators subject to transformation in acidic conditions will be affected and/or destroyed in this environment.

There are contemporary signs of disturbance within profile 1 which may be linked to the occupation groups responsible for the cooking pits identified by Västerbotten museum. However as the disturbance does occur beyond the dates identified by the museum and due to the recent disturbance of the topsoil from building works the link is not strong enough for disturbance to be used as a reliable indicator of Sámi occupation. Burning episodes, which have been identified as natural in origin, and podsolization processes are visible throughout the different analysis. Overall Prästsjödiket shows no reliable anthropogenic influence and therefore no cultural indicators of Sámi occupation.

Cultural indicators associated with anthropogenic activity have been discussed in chapter 1.2.3 with tables of cultural indicators associated with both Sámi and European activity being collated in addition to secondary tables showing the cultural indicators anticipated with Sámi activities which should still be present in acidic podzol soils (see tables 1.1 and 1.2 on page 8). Now that the analysis of the thin section slides and bulk soil samples taken at known Sámi sites has been completed the anticipated cultural indicators can be explored and confirmed and an updated table collated.

As the size and frequency of organic carbon coatings on mineral grains within and underlying charred micro-strata within the micromorphology slides have been linked to the increased availability of carbon from the charring event, a threshold limit of 3 has been set. However profile one at Prästsjödiket exceeded the threshold value of 3 indicating disturbance. This has been attributed to modern disturbance incurred when the neighbouring retail park was constructed next to the site, with waste material having been dumped randomly on-site, so although it does not indicate disturbance relevant to the historic site, it does prove, nonetheless, that anthropogenic disturbance will cause organic carbon coatings to exceed the threshold limit set in regions subject to frequent naturally occurring forest fires. Subsequently no indicators of Sámi occupation or activity have been identified at Prästsjödiket; as the pollen analysis carried out by Västerbotten museum indicated possible cereal cultivation on or near the site and no European signal was detected from the soils analysis, the cereal pollen signal has been attributed to the location of Priest lake in that it sits between this site and a later European site (Kåddis). It is probable that an early settlement attempt was made on or near the riverside Kåddis location prior to it being permanently settled and the settlement site being recorded within the tax record.

4.3 Lass Mass Heden

4.3.1 Background

Lass Mass Heden has been mapped by the Swedish Geological Society (2010) as having acid to intermediate intrusive bedrock and a podzol soil. The exact occupation period(s) are unknown as no written records are available however the only literary record of the site is of how it gained its name. Lass Mass Heden was named after the European land owner, Lars Mattson, in AD1671 which indicates that the site was occupied by the Sámi from at least the 17th century (Lycksele sameförening och Skogmuseet, 2000). However it's likely to have been occupied prior to this as the Sámi tended to re-use the same sites year after year (Mulk, 1991).

4.3.2 Study locations

From the remaining hearth stones it is evident that Lass Mass Heden has been a large Sámi site with at least 10-20 cots; a photograph of one of the remaining hearth stones is shown in figures 4.21 and 4.22. It is located next to a lake with current vegetation cover of pine trees, birch trees, moss/lichens and blaeberry bushes and several large erratic boulders; see figure 4.23 for photograph of current vegetation cover and landscape. All of the profiles appear to have formed on top of glacial sands. The locations of the soil profiles have been mapped in figure 4.25 (accompanying Google satellite image in figure 4.26).

Figure 4.21: ***In situ*** **Sámi hearth**

Figure 4.22: ***In situ*** **Sámi hearth; stones outlined**


Figure 4.23: Photograph of Lass Mass Heden showing 'typical' view


Figure 4.24: Photograph of profile 1

Profile 1 is a classic podzol soil with a dark organic layer overlying a bleached albic E-horizon, followed by a red illuvial horizon and yellow sand horizon below that. There is, however, some irregularities in the profile such as the undulating profile horizons and the collection of reddened and E-horizon material to the right of the horizon that could either have been caused by freeze/thaw actions of through tree roots; when tree roots decompose they leave gaps which will be in-filled by overlying material (see figure 4.24 for photograph of profile).

Profile 2 is located near the remains of Sámi hearths and again has the characteristics of a classic podzol. The upper horizon is silty but the grain size becomes coarser with depth with semi-rounded stones up to 6cm in length residing within the E-horizon indicating a fluvial origin

Profile 3 is a podzolic soil again but has experienced a large amount of disturbance to the middle of the profile through freeze/thaw actions. The profile has a very dark band located on top of the E-horizon that was deepest, and richest in charcoal, in a pocket located in the middle of the freeze/thaw distorted E horizon. It is impossible to determine the origin of the charcoal in the field, i.e. natural forest fire or anthropogenic, due to the natural disturbance within the profile.

Figure 4.25: Map showing location of all profiles within the Lass Mass Heden site; hearth stones indicated by stars

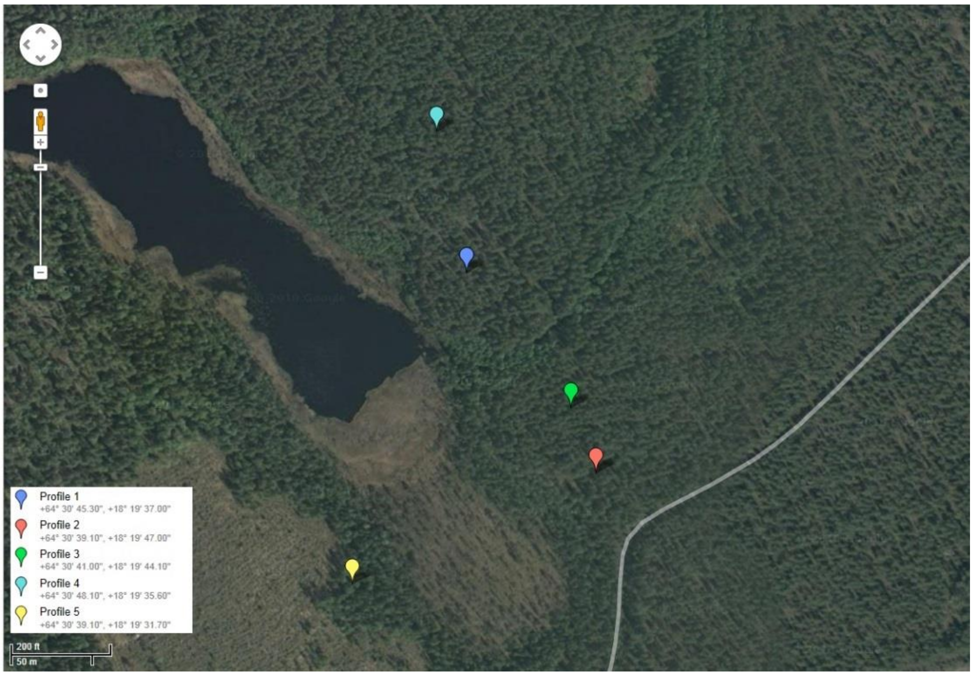


Figure 4.26: Screen grab of the Google satellite image showing profile locations (Google Maps, 2013)

Profile 4 is again a podzol that has suffered from freeze/thaw action resulting in a very disturbed E-horizon. The dark horizon overlying the E-horizon is quite thin (0.5cm thick) and intermittent.

Profile 5 is podzolic and extremely distorted. However, there are two dark micro-strata present in this profile, one overlying the E horizon and another running through the middle of it. The distortion of the E-horizon will have been caused by solifluction, most likely through freeze thaw processes, and the dark horizon located in the middle of the E-horizon could be the result of inversion of the soil as a result of these processes (Elliott, 1996). The dark horizon appearing to be in the middle of the E-horizon could possibly be the result of solifluction leading to the soil becoming inverted resulting in the thick E-horizon above the dark horizon and the thin E-horizon below; where podzolisation has temporarily occurred before the inverted soil has been buried by mineral material.

4.3.3 Chronology

Samples from profiles 3 and 5 were selected for radiocarbon dating and returned two different age sets; the dates at profile 3 ranged from AD1306-1954 and the dates at profile 5 ranged from AD259-1025; see figures 4.32 and 4.42 for the soil profile drawings showing the location of the samples within the profile, table 4.3 for the full sample information and figure 4.27 for the radiocarbon plot.

Sample A at profile 3 was taken from the topsoil and sample B from the E-horizon. The dates of AD 1521-1954 and AD 1306-1426 respectively fit with a natural, undisturbed podzol. Profile 5 looked visually disturbed in the field so three samples from within the deep but irregular shaped E-horizon were selected for dating and returned two similar dates (samples C and B) with sample X, taken from a charcoal band towards the top of the horizon, returned a later date. This supports the diagnosis that the irregular shaped horizons are caused by freeze thaw action (as samples C and B which are 4cm apart are almost equal in age) and that carbon material is illuviating down profile from the surface horizon (sample X);

distortion of the soil horizons from freeze/thaw processes is also visible in the other profiles and is therefore to be expected in the micromorphology.

The dates themselves show phasing with later dates visible in profile 5 than are seen in profile 3. Due to the level of disturbance form the freeze thaw activity as well as the associated problems of dating wood (i.e. heart wood), these dates must be limited to phasing and as evidence of natural mixing and disturbance.

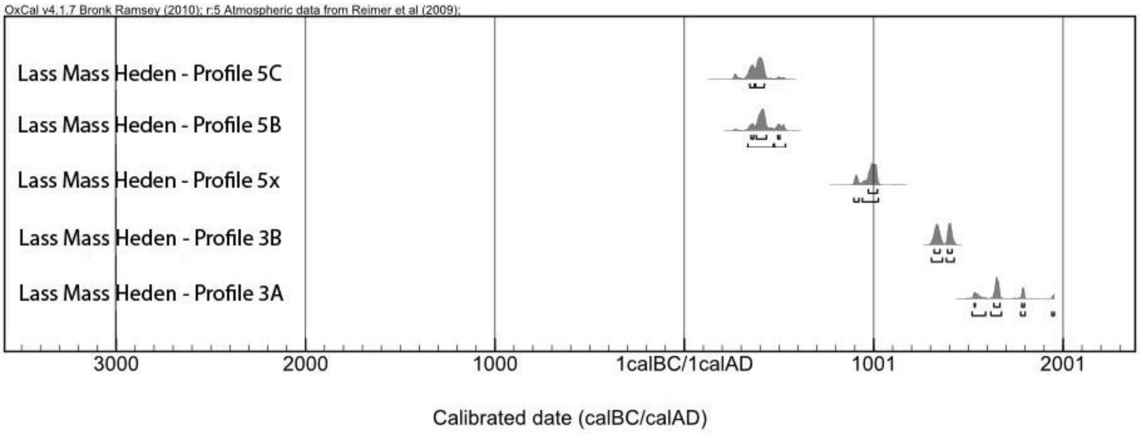


Figure 4.27: Radiocarbon plots showing the calibrated dates for the five samples dated from Lass Mass Heden

Table 4.3: Table containing information on location, type & age of all radiocarbon dated material from Lass Mass Heden

Site reference	Sample reference	Depth of sample (cm)	Lab codes	Material	Radiocarbon Age BP	Calibrated Date (≥95.4%)
Lass Mass Heden	Sample 3A	2	26871 (GU20369)	Pinus sylvestris	255±30	AD 1521-1954
Lass Mass Heden	Sample 3B	10	26872 (GU20370)	Pinus sylvestris	565±30	AD 1306-1426
Lass Mass Heden	Sample 5B	6	26873(GU20371)	Pinus sylvestris	1640±30	AD 336-535
Lass Mass Heden	Sample 5C	2	26874 (GU20372)	Pinus sylvestris	1660±30	AD 259-529
Lass Mass Heden	Sample 5x	1	26875 (GU20373)	Pinus sylvestris	1055±30	AD 896-1025

4.3.4 Micromorphology

4.3.4.1 Profile 1

4.3.4.1.1 Description

Slide 1B was taken at a depth of 5cm and encompasses a B-horizon (further split into two micro-strata) overlain by an E-horizon; see figure 4.28 for soil profile drawing and location of slide and table 4.4 for the micromorphology description tables. The B-horizon shows a visible increase in iron accumulation from the lower to the upper stratum from 15% to 40% in iron stained mineral grains and 5 to 10% in iron stained organic material.

The overlying E-horizon has a lenticular microstructure and a trace of iron stained minerals. Organic carbon coatings are common and reach size 2 with 10% of the slide consisting of black amorphous organic material which is likely to be a form of highly altered and decomposed charcoal.

Slide 1A was taken from the surface, to the right of slide 1B, and contains 5 micro-strata. From bottom to top is an E-horizon (the upper of that seen in slide 1B), an organic micro-stratum, a thin charred micro-stratum, another organic micro-stratum, another charred micro-stratum and lastly another organic micro-stratum. Due to the skewed shape of this profile these strata do not all directly overlie one another.

The E-horizon has a lenticular microstructure, trace of iron impregnated mineral grains and size 1 silt coatings around very few of the mineral grains. The organic material (total of 22%) is predominantly from root growth (10%) and from the downward movement of black amorphous material (5%) from the overlying charred stratum. The overlying charred stratum is thin, formed from very fine charcoal and is not continuous; overlies the left half of the E-horizon. This is partially overlain by an orangey-red organic accumulation, which is continuous and also overlies the E-horizon not covered by the lower charred stratum. This stratum contains a trace of quartz and feldspar grains and has been very biologically active with 45% amorphous organic material, 10% cell residue and 10% spheroidal excremental material (see table 4.4). The right hand side of this stratum is then overlain by another fresher organic accumulation. This 'fresh' organic accumulation is fragmented but wholly organic and fits well with the reindeer excrement control sample (see figure 4.29 for photographs comparing the reindeer faecal material *in situ* to the control material, a full description of the reindeer faecal material control sample is located in appendix 6). The reindeer excrement is then overlain by a second burning episode, which has left coarser charcoal, likely wood in origin, in a greater quantity; 25% of area compared to 10% in earlier burning episode and up to 5 x 2mm in size. This charcoal micro-strata is mineral rich (35%). The charcoal stratum, although continuous, is not a uniform width with the charcoal having been partially broken down.

The organic accumulation overlying the second burning phase has been very biologically active and contains a trace of quartz grains. The inclusion of quartz grains is greatest directly above the charcoal stratum and decreases towards the current land surface.

4.3.4.1.2 Interpretation

Overall, this profile shows a well-established podzol, shown by the limited iron staining, microstructure, and movement of partially dissolved charcoal throughout the E-horizon. There is no reference material to establish what alterations may occur to historical charcoal eluviating in an acidic environment but it would be reasonable to accept that charcoal may be partially to wholly dissolved in the acidic environment and re-deposited as black amorphous accumulations towards the bottom of the E-horizon and into the B-horizon. This proposal would then help explain the emerging association of organic carbon coatings with charred strata in podzols (common up to size 2 in this profile).

The E-horizon is well developed; as indicated by the lenticular microstructure, trace of iron impregnated mineral grains and the inclusion of size 1 silt coatings around very few of the mineral grains also indicate that the podzol is well developed.

The profile has undergone two burning episodes, which have left a complex map of organic material accumulations. The first light burning episode has been deemed as natural, as there are no other signs of disturbance, but the upper, secondary and more intensive burning episode has occurred in addition to a mineral deposit. The mineral material indicates disturbance as this would be a closed system with input of organic material from vegetation and animal droppings, the surface vegetation cover needs to have been broken/disturbed in order to release the mineral material; as there are organic accumulations underlying half of the charred mineral deposit the possibility of the charcoal material moving down profile can be ruled out. This charred mineral stratum therefore indicates disturbance i.e. localised soil erosion, however due to the illuvial nature of these soils the charring and erosion periods may not have occurred simultaneously and therefore cannot be linked to anthropogenic activity. The organic accumulation overlying the second burning phase is an indication of reduced disturbance over time due to the decreasing inclusion of quartz grains within it, and can be linked to the abandonment of the site

The reindeer faecal material was identified through comparison to a control sample of known reindeer excrement collected from another Sámi site. The preservation of the reindeer faecal material indicates a concentration of reindeer. As the profile is located on the outskirts of the settlement (as opposed to within a hinterland sample), it indicates that the reindeer were part of a domesticated herd; in accordance with Andersen's (2011) work detailing the difference in identifying Sámi hunters and herders.

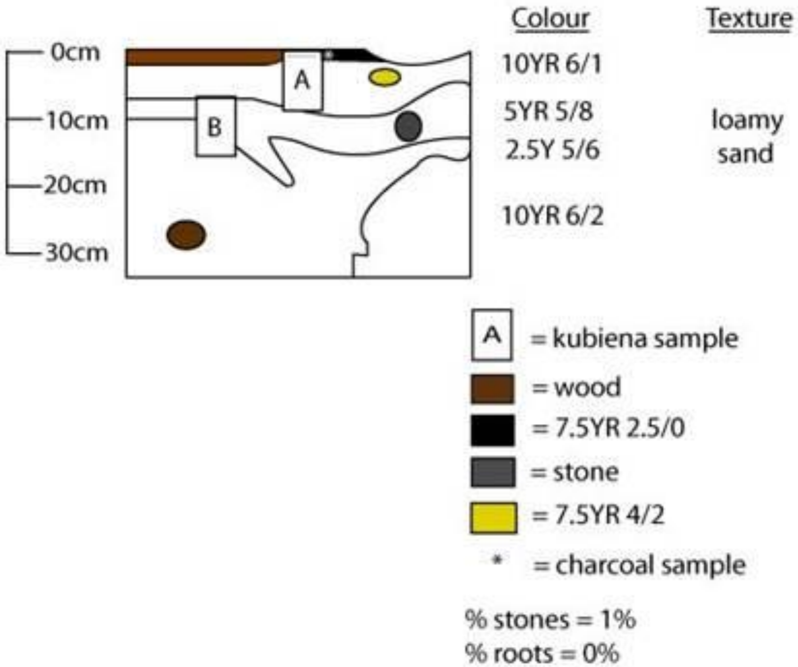


Figure 4.28: Photograph and soil profile diagram of profile 1

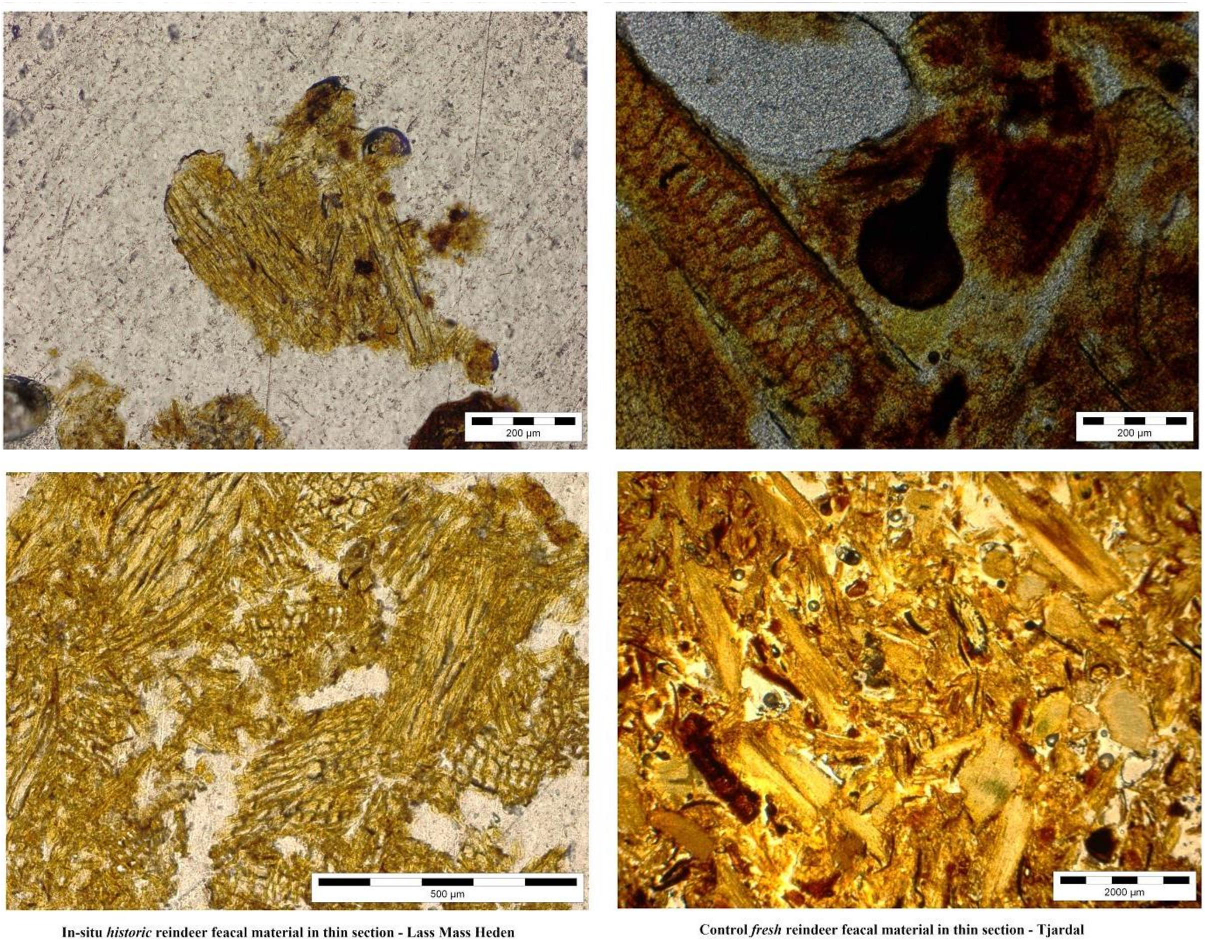


Figure 4.29: Micro photographs comparing the reindeer faecal material seen *in situ* (photographs on left) to photographs of the control sample (photographs on right); all photographs taken in PPL, top photographs taken at x10 magnification, lower left at x4 and lower right at x1.25 magnification

4.3.4.2 Profile 2

4.3.4.2.1 Description

Slide 2A was taken at a depth of 1cm and encompasses 6 micro-strata consisting of, from the bottom to the top, a B-horizon, E-horizon, charred layer, organic accumulation, secondary charred layer and secondary organic accumulation; see figure 4.30 for soil profile drawing and location of slide, figure 4.31 for a photograph, drawing and digitised annotated photograph of the slide and table 4.4 for the micromorphology description tables.

The B-horizon is iron stained (15% of mineral material) with 30% organic material, of which 15% is root material. Few organic carbon coatings, up to size 2, are present. Silt coatings are present but up to size category 1 (few) and are evidence of periglacial activity at the site and therefore its age.

The E-horizon is partially developed with no iron impregnated material and an emerging lenticular structure developing from the distribution of clay sized particles within the overall weak crumb pedality. Some charcoal, both fragmented (trace) and partially dissolved (10% black amorphous organic material) has leached down into the profile from the overlying charred stratum that may have been helped by the abundant (10%) root material. Organic carbon coatings are still present up to size band 1 (very few). Silt coatings are again present at size level 1 as was seen in the B-horizon but at a decreased rate; very few compared to the few seen in the B-horizon.

The overlying charred stratum is coarse in size (maximum size 10x6 mm), wood or shrub in origin and fractured in nature; the charred material is a mixture of charcoal (20%) and lignified tissue (25%). All fragments are aligned in the same direction, parallel to the underlying E-horizon, and occur at a uniform depth across the slide.

The charred stratum is overlain by an organic rich A-type horizon, which is a mixture of fresh root material and highly reworked organo-mineral b-fabric.

This is then overlain by a further, secondary, charred stratum indicating a second burning event. The charred material here is again a mixture of charcoal (20%) and lignified tissue (5%) but is more fragmented and, therefore, smaller in size (max 4x4mm) than the primary burning event. The stratum is highly mixed from biological activity and root growth and contains a mixture of charred material, organic material (from fresh to amorphous), and limited organo-mineral b-fabric material and quartz grains (2%). Organic carbon coatings are also present on the mineral grains (very few) up to size band 2.

There is then a final shallow organic accumulation at the top right hand corner of the slide which is almost wholly fresh root type material with a quartz grains (2%) and very rare organic carbon coatings of up to size band 2. Although there is a trace of lignified tissue there is no charcoal or organo-mineral b-fabric.

4.3.4.2.2 Interpretation

The silt coatings were originally thought to be indicative of disturbance but after much discussion with Richard Macphail, who has worked with soils in this area, it transpired that the compact coatings were periglacial in origin, the inclusion and location of which will become of importance at the European sites. The elevated availability of carbon from the burning episodes is apparent through the inclusion of charcoal and black amorphous material in both the E and underlying B-horizon, which has percolated down profile.

The organic accumulations have been more mineral rich in this profile than in previous sites and profiles, indicating a higher level of disturbance at the site; as indicated through the mineral accumulations. This could be above ground disturbance, either through direct movement above ground, e.g. through traffic of animals, or through indirect erosion processes. It could also be from soil biota. The organic accumulation has been biologically active but not in the same mite excrement rich, almost wholly organic fashion as is typical of these strata, but rather as a partially formed organo-mineral b-fabric; this may be related to the increased mineral input at the site.

The current lack of spheroidal excremental material does not indicate that it never existed as it may have already been reworked into the soil, however the lack of any current spheroidal material indicates that the stratum has always had a reduced level of biological activity which is likely to have been the reason for formation of the initial stages of an A-horizon below the second burning episode.

The initial charred material deposit fragments are aligned in the same direction, parallel to the underlying E-horizon, and occur at a uniform depth across the slide indicating that they have been deposited in a single event, most likely from the same wood fragment, which has been partially charred and then fractured naturally over time. This material is overlain with an organo-mineral b-fabric which has not been seen in the organic accumulations overlying charred strata at Sámi sites prior to this, and indicates that, due to the formation of A stratum type material and the level of iron depletion, that the underlying charred stratum and subsequent organic accumulations are historic and that a natural A-horizon had begun to form after the organic formation exhausted itself.

The second burning episode stimulated a further accumulation of organic material which formed alongside a mineral accumulation as before. The highly mixed nature of this micro-stratum alongside the lack of any spheroidal excremental material indicates a highly biologically active environment which has now ceased. The cessation of biological activity and reworking of the soil then allowed the accumulation and development of a fresh, undisturbed organic rich stratum which as it again has mineral inclusions indicates that soil erosion near the site has occurred historically and continued on some level to contemporary times.

The charred material is again overlain with an organic accumulation which as it's undisturbed and contains no direct evidence of anthropogenic activity, indicates that at some point after the second burning episode the site was abandoned. After a further period of time the biological activity ceased, due to the re-development of poor conditions within the mixed charred/organic stratum through lack of nutrients, which has then allowed the continuing development of organic material and introduced mineral grains to accumulate without disturbance from biological activity.

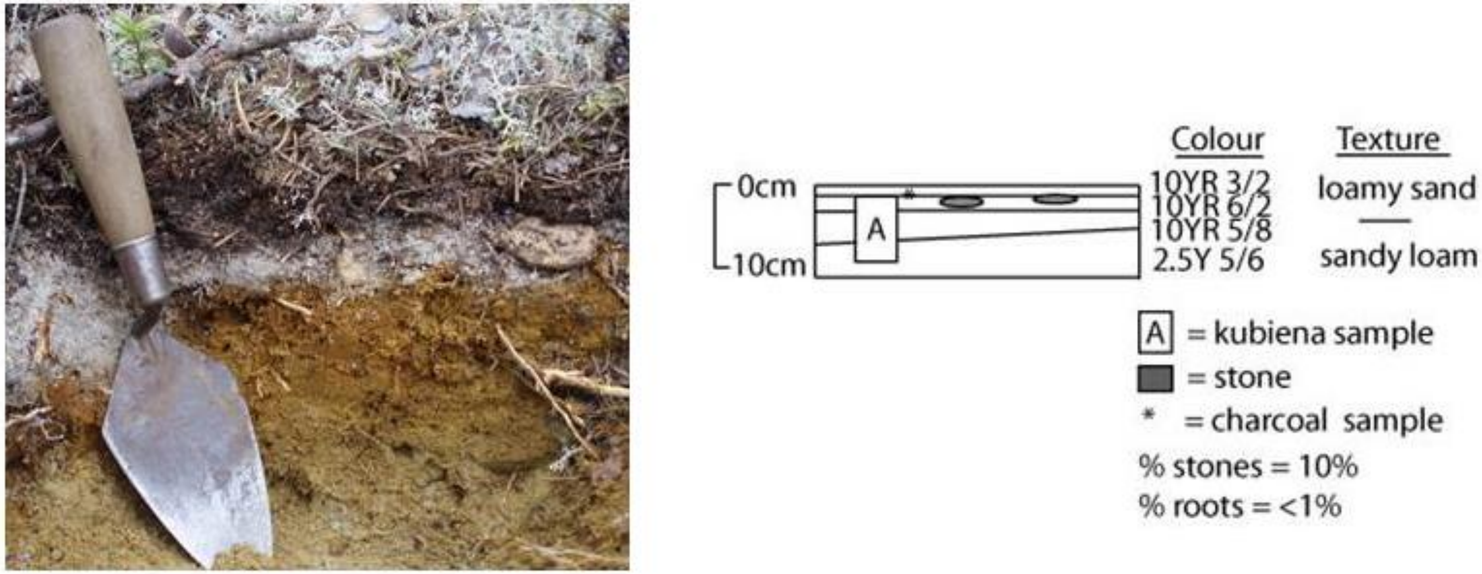
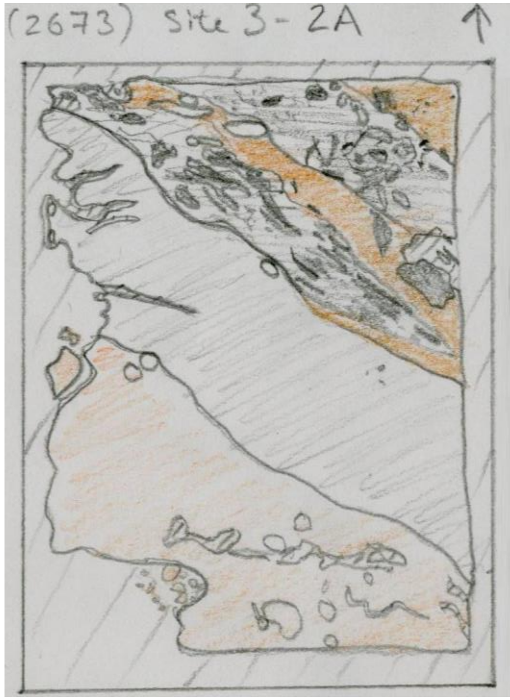


Figure 4.30: Photograph and soil profile diagram of profile 2

Photograph of slide

Digitised photograph of slide



Original drawing of slide

Figure 4.31: Photograph, diagram and digitised drawing of Lass Mass Heden profile 2A

4.3.4.3 Profile 3

4.3.4.3.1 Description

Slide 3A was taken at a depth of 0cm from the current surface and encompasses a 4 micro-strata and a further two organic inclusions. These micro-strata from bottom to the top are an E-horizon (containing the two organic inclusions), a charred stratum and two organic strata; see figure 4.32 for soil profile drawing and location of slide and table 4.4 for the micromorphology description tables.

The E-horizon is well developed with the development of the lenticular microstructure increasing with depth and there is only a trace of iron stained mineral grains present. There are very rare size 1 periglacial silt coatings, which confirm the age and well developed nature of the podzol. The organic content of the micro-stratum is predominantly root material (12%) with the remainder being strongly decomposed or charred; 16% is amorphous organic material of which 10% is black. The two organic inclusions within this stratum occur to the left of the slide and are both groups of root material with a surrounding accumulation of iron (20% of mineral material).

The charred stratum both overlies and almost cuts through the E-horizon, see figure 4.24 for slide photograph, with evidence of disturbance/mixing of the two strata which increases towards the top of the E-horizon. The shape of the charred deposit along with the level of mixing is reminiscent of extreme frost heave. The charred material has been fractured and disturbed by root growth and, especially within the lower quarter of the stratum, has begun to transform to a partially amorphous state. Organic carbon coatings are common up to size grade 4.

The organic stratum directly overlying the charred material is almost wholly organic with only a trace of silt sized mineral grains but is predominantly formed from spheroidal excremental material (40%). The organic material includes several spruce needles (4 whole, 2 fragments); see figures 4.33 and 4.34 for photographs.

A second organic stratum with different characteristics overlies the first. The two organic micro-strata are visibly distinct from one another with the naked eye due to a difference in organic material. The organic material in the upper strata is deeply decomposed (62%) with 30% of the stratum appearing as almost completely homogenous (yellow amorphous material); the upper accumulation is also marked by an elevation of mineral material (2% compared to a trace in the lower organic accumulation) with size 1 organic carbon coatings present on very few of the mineral grains. No parenchymatic tissue is present.

4.3.4.3.2 Interpretation

The high percentage of black amorphous organic material in the E-horizon, which has the same diagnostic properties as the partially dissolved charcoal seen in the E-horizons of profile 1 and 2, as well as the inclusion of size band 3 organic carbon coatings on the mineral grains (rare), are the product of the overlying charred micro-strata; the material has moved down profile. The iron accumulations around the roots indicate that the root material grew during a wet period which led to the attraction and oxidation of iron around the roots.

The lower stratum has been very biologically active with 40% of the stratum containing preserved spheroidal excremental material. The sharp boundary between the upper and lower organic strata indicates a significant change in the soil conditions with the inclusion of spruce needles indicating a natural woodland environment which has not been subject to clearance. The upper stratum has homogenised and decomposed organic material, which is reminiscent of peat accumulations minus the lignified tissue. The 2% spheroidal excremental pedofeatures seen in the stratum are located within the area of homogenised yellow amorphous material and has therefore been introduced by burrowing micro fauna, which would not be present in peat. As a result, the decomposed state of the organic material and the reduced visibility of spheroidal excremental pedofeatures indicate that the stratum has reworked itself until it reached a state of biological exhaustion, which has then allowed the current poor environment to develop; this is supported by the presence of the sclerotia. The slight increase in mineral content from a trace in the lower to 2% in the upper organic stratum along with the very few size 1 organic carbon coatings indicates a slight increase in local disturbance but it is still occurring on a very small scale.

Figure 4.33: Spruce needle, PPL x4 mag

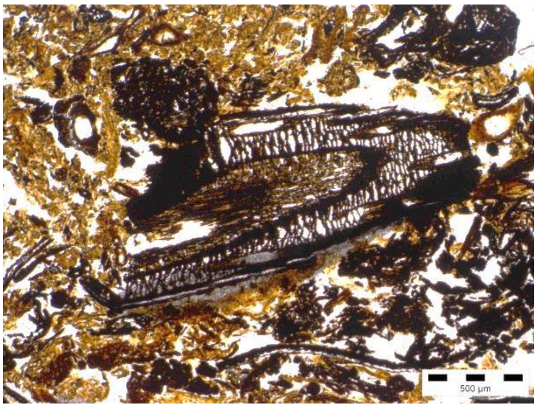


Figure 4.34: Spruce needle, PPL x4 mag

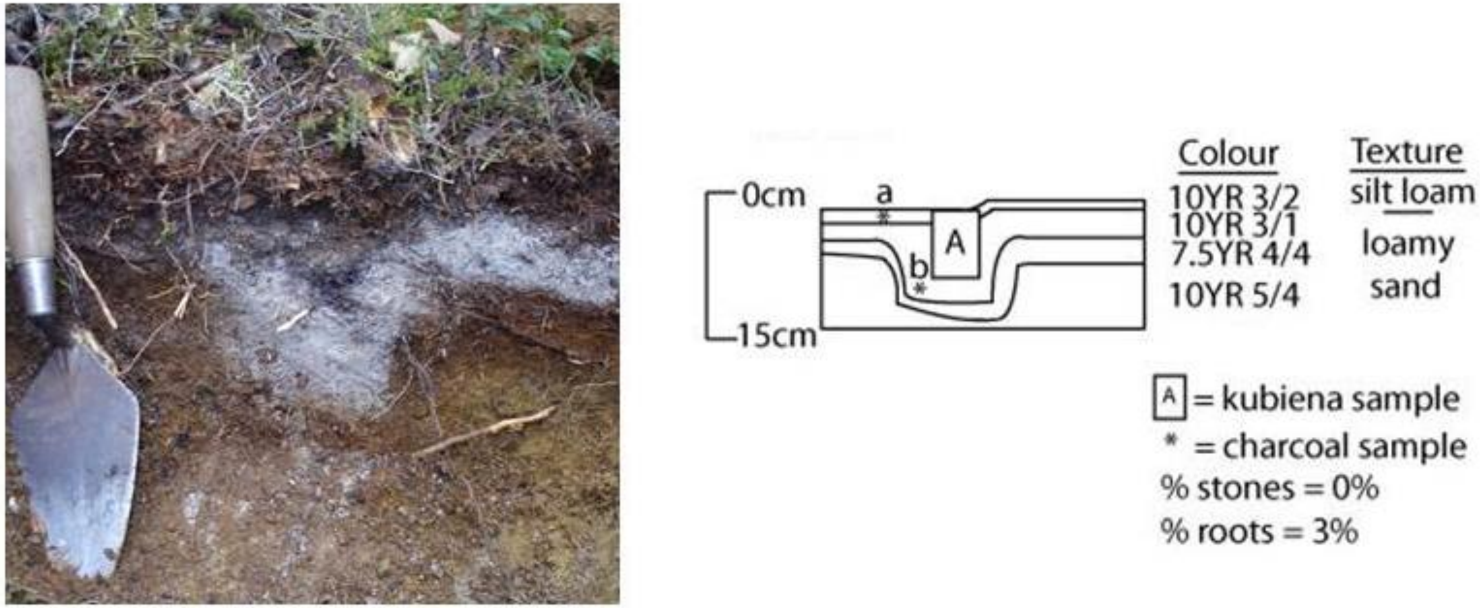


Figure 4.32: Photograph and soil profile diagram of profile 3

4.3.4.4 Profile 4

4.3.4.4.1 Description

Slide 4A was taken from the surface of the profile and encompasses 5 micro-stratum which from bottom to the top are the B-horizon, E-horizon (which has a trace of charcoal overlying it), an organic stratum, a second E-horizon and a second organic stratum; see figure 4.35 for soil profile drawing and location of slide and table 4.4 for the micromorphology description tables.

The B-horizon is well developed with an iron rich (30%) crumb microstructure. Periglacial silt coatings are very rare (size 1), showing the highest levels of iron accumulation at the inner and outermost areas of the coating, and the organic material is predominantly root material as.

The lower E-horizon is moderately to weakly developed as although only a trace of the mineral material is iron stained, the very weak lenticular microstructure is only detectable from silt accumulations and is overall still a weak crumb microstructure rather than lenticular. Movement of material down through the stratum is apparent through the movement of charcoal (trace of charcoal, 10% amorphous black material) and lignified tissue (5%) from the top of the E-horizon to half way down the profile.

The overlying organic accumulation changes in character, from a very biologically active excremental rich accumulation (30%) to coarser sized fractured organic material, and then amorphous material. The amorphous organic material has more mineral inclusions than the remainder of the stratum and there is no clear boundary between this and the overlying second E-horizon; as there is a secondary E-horizon overlying it, this stratum is a buried past land surface.

The second E-horizon is poorly developed as although it has no iron staining it has a crumb microstructure. The top central area of this micro-stratum shows biogenic features by the mixing of the lower and upper organic micro-strata.

The second organic accumulation contains a mixture of large fragments of organ residues, which is either still fresh (with parenchymatic tissues) or humified and fine organic material. Mineral inclusions out-with the mixed central area is limited to a trace.

4.3.4.4.2 Interpretation

The movement of material throughout the E-horizon, such as charcoal and lignified tissue, indicates that the podzol is very well drained; as a result, there is no clear charred stratum overlying the E-horizon. The free draining nature of the profile may be reason for the organic accumulation even with the low intensity burning event.

The second E-horizon is made up from material derived from erosion elsewhere on site; indicated nu the depth of the accumulation and size of the mineral grains (up to size 5). As the mineral material is completely iron free, it can be suggested that either the material has originated as E-horizon material from elsewhere or that landscape erosion has exposed it and it's been deposited here. Either way the material has not been in situ long enough for the typical lenticular microstructure to form; as there are no silt capping's present the material would have been from the upper E-horizon. Although the size of the grains is different it is possible that this accumulation was deposited during the same period as the upper mineral rich charred stratum in profile 3, and would indicate that due to the courser nature of the mineral grains that profile 4 is closer to the erosion source.

The 2% spheroidal excremental material present in the second organic accumulation indicates that although the stratum has been biologically active, the size of the organic fragments present indicates that it has been on a much smaller scale than the lower stratum. This may be related to the environment on which the organic material is accumulating/forming on, as although there is a trace of charcoal, it has originated elsewhere and there is no evidence to suggest that there was a second burning episode on the secondary E-horizon in order to stimulate this organic accumulation. The large size of the organic material in the overlying accumulation indicates that there has been no direct disturbance to this site before the accumulation of the second E-stratum, which is most likely to have formed from localised landscape erosion. The subsequent organic accumulation has been deemed as naturally occurring due to the freely draining nature of the soil and the input of leaf litter from the surrounding woodland; fragmented spruce needles common.

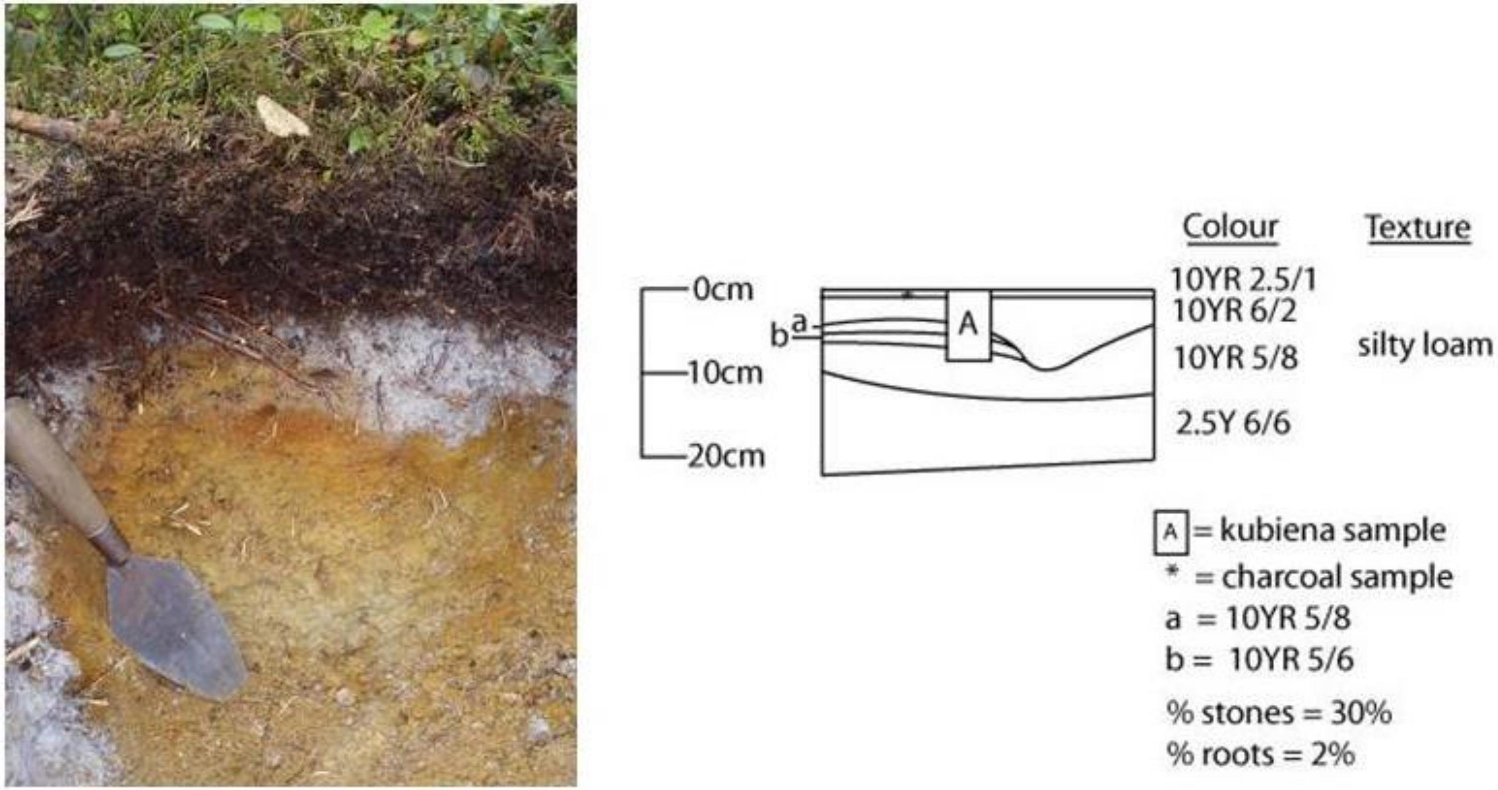


Figure 4.35: Photograph and soil profile diagram of profile 4

4.3.4.5 Profile 5

4.3.4.5.1 Description

Slide 5A was taken from the surface of the profile and encompasses 5 micro-strata, which from bottom to the top are the B-horizon, which has been split into three further strata, a lower E-horizon, a mixed charcoal and E-horizon, and an upper E-horizon; see figure 4.42 for soil profile drawing and location of slide and table 4.4 for the micromorphology description tables.

There are two micro-strata in the B-horizon. They are very similar in composition however the groundmass colour changes from yellow in the lower to brown in the upper stratum, and the frequency and size of the silt capping decreases from size band 3 capping being common in the lower stratum to a few size band 2 capping in the upper stratum (see figures 4.36 and 4.37 for photographs). The coatings in the lower stratum show phases of accumulation from coarser grains on the surface of the mineral to a fine coating on the outer edge, as well as variations in iron staining with the inner and outermost bands of the coatings typically being stained more than the central area; see figures 4.38 and 4.39 for photographs. The lower stratum has a well-developed, gravel based crumb microstructure, which is seen at a reduced level in the upper B-horizon. Both strata contain root material (15%) as is typical of the B-horizons studied and do not display any indicators of disturbance or amendment.

The lower E-horizon is moderately developed, although still iron rich for an E-horizon (5% of mineral material iron stained), starting with a clearer lenticular microstructure becoming more compact with higher levels of fine mineral material towards the top of the stratum with root material throughout (15%). Black punctuations and amorphous organic material are present from the upper mixed stratum and there is no clear boundary between the two.

The mixed E and charred stratum contains a combination of charcoal, which ranges in form from fragmented (20%) to partially dissolved (10%), E-horizon mineral grains and traces of organo-mineral b-fabric reminiscent of A-horizon material; see figures 4.40 and 4.41 for photographs of partially dissolved charcoal fragments. Although the materials are mixed, the microstructure is crumb with lenticular patterns beginning to emerge. The charred material is in general parallel to the lenticular pattern. This stratum then develops into the upper E-horizon, which is very similar in composition with no clear boundary between the two. The only difference is the slight increase in organic material (35% compared to 31%) and a reduced level of charcoal; a trace compared to 20% in the underlying mixed stratum.

4.3.4.5.2 Interpretation

Overall, this is a well-developed podzol which has formed on a gravel bed; sub-rounded mineral material reminiscent of water eroded material. The charred stratum within the E-horizon is parallel to the lenticular pattern within the microstructure, indicating that any mixing of the material was historic; as a freeze thaw pattern overlies any evidence of mixing. As there are no additional signs of disturbance, the burning episode has been deemed as natural. The small traces of A-horizon material captured indicate a possible past land surface, which could be linked to the burning event. However as there is no clear boundary between the mixed and upper E-horizon strata, it indicates that the burning activity was low in intensity and did not have enough impact to initiate an accumulation of organic material.

The movement of material down profile is evident and is linked to the inherent illuviation processes. However as root growth is prominent throughout the stratum (7% of total), this will also have been a source of disturbance. Unusually for a podzol, the organic A-horizon has been too thin to be captured in the slide and indicates, especially for such a well-developed podzol, anthropogenic activity through the removal of the associated turf.

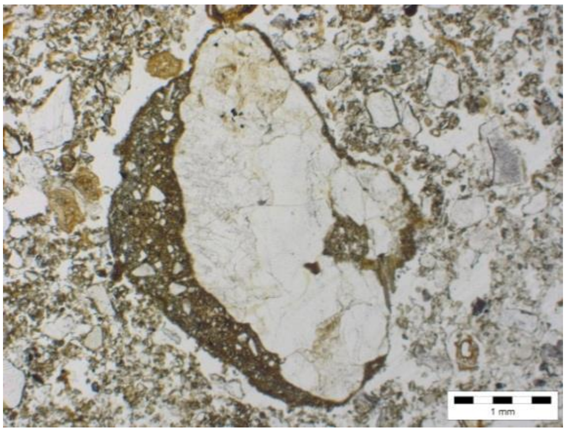


Figure 4.36: Silt coating, PPL x2 mag

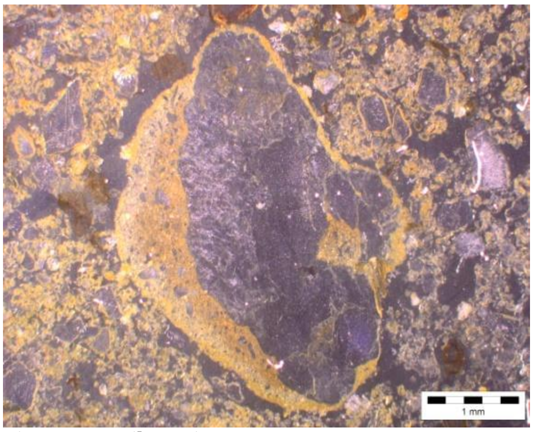


Figure 4.37: Silt coating, OIL x2 mag

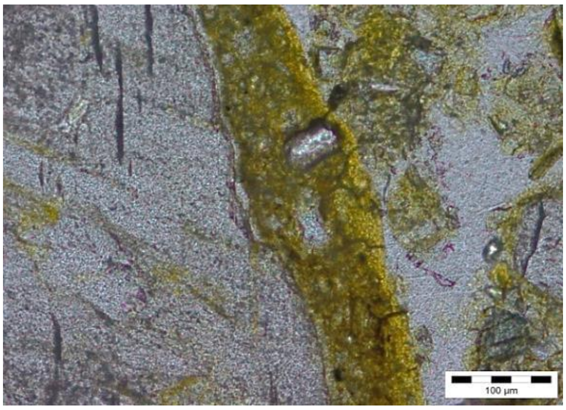


Figure 4.38: Layered silt coating, PPL x20 mag

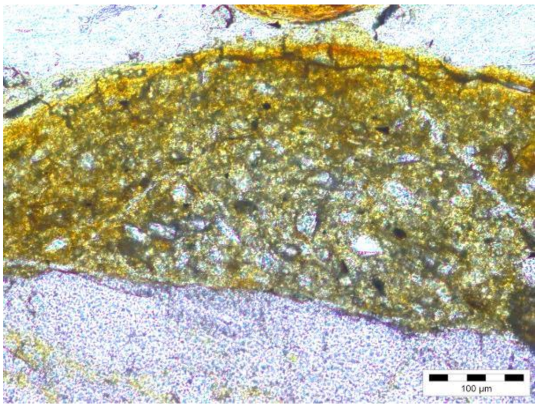


Figure 4.39: Layered silt coating, PPL x20 mag

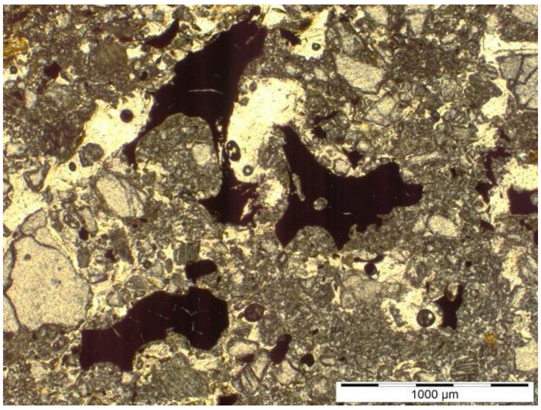


Figure 4.40: Partially dissolved charcoal, PPL x2 mag

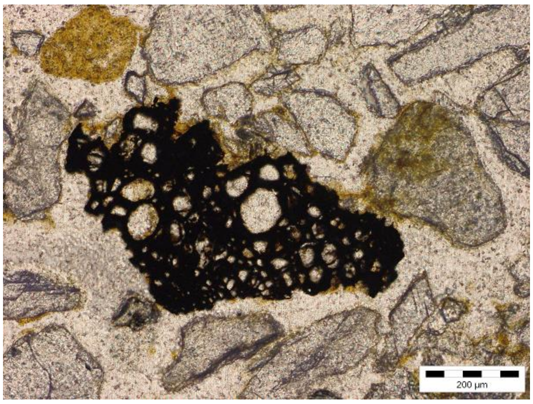


Figure 4.41: Partially dissolved charcoal, PPL x10 mag

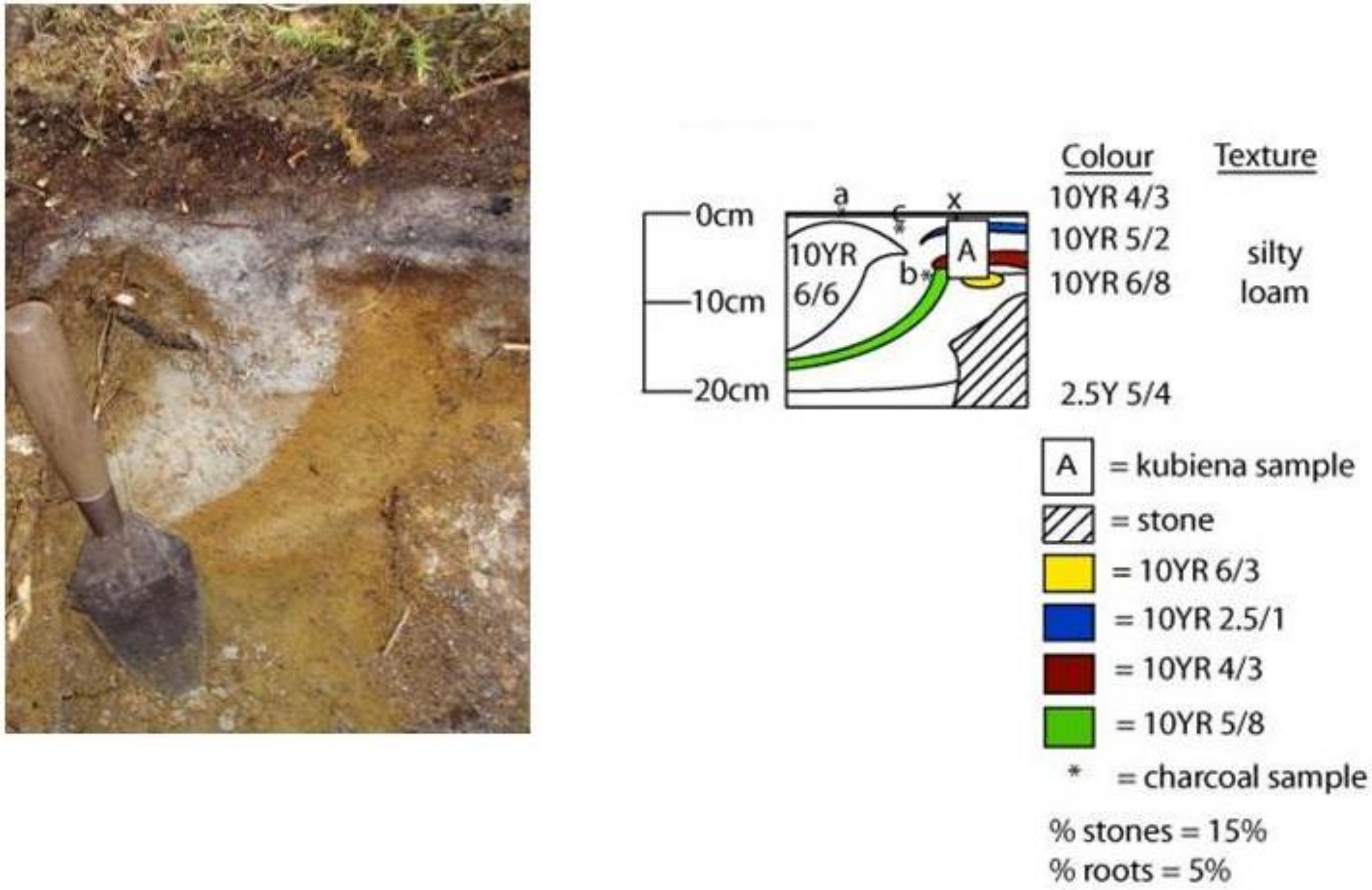


Figure 4.42: Photograph and soil profile diagram of profile 5

4.3.4.6 Summary

The emerging pattern of the charring of surface vegetation from natural forest fires followed by an organic accumulation is evident at this site and offers further insight into the long term effects of this activity, as well as how the charred material is transformed in a podzolic environment.

Several of the profiles at this site display not only the organic accumulations initiated by the burning episode, but also how these organic accumulations which were very biologically active at the start, become poorer over time till the point where they are exhausted. Where secondary burning episodes have occurred above these exhausted organic strata, the accumulation of organic material is renewed and is further evidence of the link between the charring of the soil surface initiating an accumulation of organic material and more favourable conditions promoting biological activity, see profile 2 for a clear example; as the radiocarbon dating of wood type material is prone to accuracy problems the time taken for a newly formed organic accumulation to exhaust itself cannot be determined. There are, however, always exclusions to the rule and in this case it is profile 4, which is a well-drained podzol and only needed a low key burning episode to initiate an accumulation of organic matter. Once this accumulation was buried by a secondary accumulation of E-horizon material, a secondary organic accumulation began forming without the trigger of a secondary burning episode. The fact that organic material began accumulating after such a low key burning episode shows that this profile was already very close to meeting the requirements for this to occur naturally, and consequently it was able to restart naturally without the trigger required in other areas.

The charred material within these podzol soils undergo a transformation not seen in less acidic soil types, namely a transformation over time to a partially dissolved state where the structure within the charcoal fragment becomes homogenised and the edges of the fragment appear blunted (see figures 4.40 and 4.41 for photographs). Partially dissolved charcoal can be seen in slide 1B, 3A and 5A at this site but also in a number of samples taken at the other study sites. The dissolving nature of the charcoal fragments over time could also be related to a possible increase in organic carbon coatings in minerals in charred profiles. Organic carbon coatings indicate disturbance (Simpson, *pers. comm*) but does the elevated levels typically seen in or below charred strata indicate high levels of disturbance or are they related to the increased availability of carbon, especially in a naturally alluviating soil? Typically for this site the profiles show little to no evidence of disturbance and have organic carbon coatings present on very few of the mineral grains within or underlying the charred stratum up to size band 2, but the charred stratum in profile 3, which is a greatly disturbed profile, has size 4 carbon coatings common in the charred stratum. As a result it's been concluded that in acidic podzolic environments where the availability of carbon has been increased due to a burning episode, followed by partial dissolution of the charred material (which can readily be transported by illuviation processes), that organic coatings of size band 2 or below occurring in a frequency of very few or less, need to occur alongside other evidence before an interpretation of surface disturbance can be reached; they need not be dismissed completely as the elevated frequency and size of coatings above the threshold value seen in profile 3 is proof that disturbance will cause organic carbon coatings to form.

However the key finding from the micromorphological analysis is the inclusion of reindeer faecal material in profile 1 which can be linked to reindeer husbandry, a known Sámi occupation. The inclusion of reindeer faecal material can therefore be used as an indicator of Sámi activity.

Table 4.4: Micromorphology description tables for Lass Mass Heden slides

				Coarse mineral material (>10µm)														Coarse Organic material (>10µm)								Fine Organic Material (<10µm)				Pedofeatures				Structure			
Profile	Micro-strata	Depth (cm)	Quartz %	Quartz maximum size	Feldspar %	Feldspar maximum size	Siltstone %	Siltstone maximum size	Mica %	Mica maximum size	Glauconite %	Arrangement of minerals	Fine mineral material (<60µm)	Silt coating frequency	Silt coating maximum size	Organic carbon coatings frequency	Organic carbon coating maximum	Organ residue	Tissue residue	Largest tissue residue (mm)	Lignified tissue	Sclerotia	% Charcoal	Largest charcoal	Cell residue	Amorphous black	Amorphous yellow	Amorphous brown	Amorphous red	Excremental (*Spheroidal*) 50-100µm	Fe impregnated mineral material %	Fe impregnated organic material %	% void space	Microstructure	Course material arrangement	Groundmass b fabric	C/F ratio
1A	1	0	t	1	-	-	-	-	-	-	-	SR	Grey with low IC	-	-	-	-	15	10	50 x 150	t	-	-	-	5	5	5	10	-	10	-	-	40	Weak pedality, crumb	Partially sorted & accommodated	Close fine enaulic, brown SS	2/1
	2		20	3	10	2	5	1	t	1	-	SR	Grey with low IC	-	-	-	-	-	-	-	5	-	25	5	5	10	t	t	t	-	-	-	20	Weak pedality	Partially sorted & accommodated	Close fine enaulic, brown SS	3/1
	3		-	-	-	-	-	-	-	-	-	-	N/A	-	-	-	-	10	40	100 x 600	-	-	-	-	5	5	5	5	t	t	-	-	30	Weak pedality	Partially sorted, un-accommodated	Single spaced enaulic, undifferentiated B-fabric	5/1
	4		t	2	t	2	-	-	t	1	-	SR	Grey + low IC	-	-	-	-	-	10	200 x 50	-	-	-	-	10	10	10	20	5	10	-	-	20	Weak pedality	Partially sorted, un-accommodated	Single spaced enaulic, brown SS	2/1
	5		30	3	10	2	2	1	2	1	-	SR	Grey + low IC	2	3	2	3	5	5	150 x 50	-	-	t	1	5	5	2	-	t	t	t	5	30	Moderate pedality, lenticular	Un-sorted, partially accommodated	Close porphyric, grey SS	4/1
1B	1	5	30	2	10	1	5	1	t	1	-	SR	Grey + low IC	-	-	2	2	5	-	-	-	-	t	1	5	10	5	5	t	-	t	t	20	Weak pedality, lenticular	Partially sorted, well accommodated	Double spaced porphyric, grey SS	1/3
	2		30	1	5	1	2	1	t	1	-	SR	Grey + low IC	2	1	2	4	-	5	50 x 25	-	-	-	-	10	10	20	t	t	-	40	10	20	Weak pedality, granular	Partially sorted, well accommodated	Single spaced porphyric, brown SS	2/1

Note: Micro stratum 3 of slide 1A has been identified as a deposit of reindeer faecal material

				Coarse mineral material (>10µm)														Coarse Organic material (>10µm)								Fine Organic Material (<10µm)				Pedofeatures				Structure			
Profile	Micro-strata	Depth (cm)	Quartz %	Quartz maximum size	Feldspar %	Feldspar maximum size	Siltstone %	Siltstone maximum size	Mica %	Mica maximum size	Glauconite %	Arrangement of minerals	Fine mineral material (<60µm)	Silt coating frequency	Silt coating maximum size	Organic carbon coatings frequency	Organic carbon coating maximum	Organ residue	Tissue residue	Largest tissue residue (mm)	Lignified tissue	Sclerotia	% Charcoal	Largest charcoal	Cell residue	Amorphous black	Amorphous yellow	Amorphous brown	Amorphous red	Excremental (*Spheroidal*) 50-100µm	Fe impregnated mineral material %	Fe impregnated organic material %	% void space	Microstructure	Course material arrangement	Groundmass b fabric	C/F ratio
	3		30	2	5	1	2	1	t	1	-	SR	Grey + low IC	-	-	-	-	5	5	50 x 25	-	-	-	-	10	t	10	5	2	2	30	10	15	Weak pedality, granular	Un-sorted, well accommodated	Single spaced porphyric	2/1
	4		30	2	5	1	2	1	t	1	-	SR	Grey + low IC	2	1	-	-	5	-	-	-	-	-	-	10	t	20	10	t	-	40	15	20	Weak pedality, granular	Unsorted, well accommodated	Single spaced porphyric	2/1
	5		30	2	10	2	5	1	t	1	-	SR	Grey + low IC	3	2	2	4	5	5	25 x 25	-	-	-	-	10	t	10	5	t	-	15	5	20	Weak pedality, granular	Un-sorted, well accommodated	Close porphyric, yellow SS	3/1
2A	1	1	2	1	t	1	-	-	-	-	-	SR	Grey + low IC	-	-	2	1	5	20	150 x 100	5	-	5	1	10	5	5	t	-	-	-	10	40	Weak pedality, granular	Partially sorted, unaccommodating	Single spaced enaulic, brown SS	3/1
	2		2	1	-	-	-	-	-	-	-	SR	Grey + low IC	-	-	2	3	5	-	-	5	-	20	5	2	15	10	5	-	-	-	5	30	Weak pedality, crumb	Partially sorted, un-accommodated	Single spaced enaulic, brown SS	3/1
	3		t	1	-	-	-	-	-	-	-	SR	Grey + low IC	-	-	-	-	15	20	50 x 100	t	-	-	-	10	5	t	10	-	-	-	t	40	Weak pedality crumb	Partially sorted & accommodated	Single spaced enaulic, brown SS	2/1
	4		10	2	2	1	t	1	t	1	-	SR	Grey + low IC	-	-	-	-	5	-	-	25	-	20	6	5	10	5	t	t	-	-	-	20	Weak pedality crumb	Partially sorted & accommodated	Single spaced enaulic, brown SS	3/1

				Coarse mineral material (>10µm)														Coarse Organic material (>10µm)								Fine Organic Material (<10µm)				Pedofeatures				Structure			
Profile	Micro-strata	Depth (cm)	Quartz %	Quartz maximum size	Feldspar %	Feldspar maximum size	Siltstone %	Siltstone maximum size	Mica %	Mica maximum size	Glauconite %	Arrangement of minerals	Fine mineral material (<60µm)	Silt coating frequency	Silt coating maximum size	Organic carbon coatings frequency	Organic carbon coating maximum	Organ residue	Tissue residue	Largest tissue residue (mm)	Lignified tissue	Sclerotia	% Charcoal	Largest charcoal	Cell residue	Amorphous black	Amorphous yellow	Amorphous brown	Amorphous red	Excremental (*Spheroidal*) 50-100µm	Fe impregnated mineral material %	Fe impregnated organic material %	% void space	Microstructure	Course material arrangement	Groundmass b fabric	C/F ratio
	5		25	2	15	1	5	1	2	1	t	SR	Grey + low IC	1	3	1	3	5	5	50 x 250	-	-	t	2	2	10	2	t	t	-	-	5	30	Weak pedality crumb	Well accommodated, unsorted	Close enaulic grey SS	3/1
	6		20	3	10	2	10	2	2	2	t	SR	Grey + low IC	1	4	2	4	10	5	50 x 100	-	-	-	-	5	t	t	10	-	-	15	5	30	Weak pedality crumb	Un-sorted, partially accommodated	Single spaced enaulic, grey-yellow SS	2/1
3A	1	0	5	1	t	1	-	-	-	-	-	SR	Grey + low IC	-	-	1	3	5	5	50 x 100	5	1	t	1	10	2	30	20	-	2	-	t	20	Weak pedality, crumb	Well sorted & partially accommodated	Single spaced enaulic, orangey brown SS	1/1
	2		t	1	-	-	-	-	-	-	-	SR	Grey + low IC	-	-	-	-	5	5	50 x 50	t	-	-	-	5	t	10	5	-	40	-	-	30	Weak pedality granular	Partially sorted & well accommodated	Close fine enaulic, undifferentiated B -fabric	1/2
	3		20	2	5	2	2	1	2	1	-	SR	Grey + low IC	-	-	4	5	2	2	50 x 50	15	-	10	5	5	15	t	5	t	-	t	-	20	Weak pedality, crumb	Unsorted + partially accommodated	Single spaced fine enaulic, grey SS	3/1
	4		25	2	15	2	10	1	t	1	-	SR	Grey + low IC	1	1	3	2	10	2	50 x 100	-	-	-	-	t	10	2	2	2	-	t	5	20	Moderate pedality, lenticular	Unsorted, partially accommodated	Single spaced fine enaulic, grey SS	2/1
	5		20	1	10	1	5	1	5	1	-	SR	Grey + low IC	-	-	-	-	-	5	50 x 50	-	-	-	-	10	-	t	20	t	-	20	10	25	Weak pedality, crumb	Partially sorted & accommodated	Close fine enaulic, grey/brown SS	3/1

			Coarse mineral material (>10µm)															Coarse Organic material (>10µm)								Fine Organic Material (<10µm)				Pedofeatures				Structure			
Profile	Micro-strata	Depth (cm)	Quartz %	Quartz maximum size	Feldspar %	Feldspar maximum size	Siltstone %	Siltstone maximum size	Mica %	Mica maximum size	Glauconite %	Arrangement of minerals	Fine mineral material (<60µm)	Silt coating frequency	Silt coating maximum size	Organic carbon coatings frequency	Organic carbon coating maximum	Organ residue	Tissue residue	Largest tissue residue (mm)	Lignified tissue	Sclerotia	% Charcoal	Largest charcoal	Cell residue	Amorphous black	Amorphous yellow	Amorphous brown	Amorphous red	Excremental (*Spheroidal*) 50-100µm	Fe impregnated mineral material %	Fe impregnated organic material %	% void space	Microstructure	Course material arrangement	Groundmass b fabric	C/F ratio
	6		15	2	5	1	2	1	2	1	-	SR	Grey + low IC	-	-	-		25	5	50 x 50	-	-	-	-	5	2	2	5	t	-	20	5	25	Weak pedality, crumb	Partially sorted & accommodated	Close fine enaulic, grey/brwn SS	3/1
4A	1	O	t	2	-	-	-	-	-	-	-	SR	Grey + low IC	-	-	1	2	15	10	300 x 100	5	-	t	2	15	10	10	10	-	2	-	-	20	Weak pedality, crumb	Unsorted & partially accommodated	Single spaced enaulic, yellow brown SS	2/1
	2		25	1	5	1	5	1	2	1	-	SR	Grey + low IC	-	-	2	4	2	15	100 x 50	2	1	-	-	5	5	10	5	-	t	-	-	20	Weak pedality, crumb	Partially sorted & accommodated	Single spaced enaulic, yellow SS	2/1
	3		5	1	-	-	-	-	-	-	-	SR	Grey + low IC	-	-	2	2	t	10	100 x 150	t	-	-	-	10	1	2	2	t	30	-	10	40	Weak pedality, crumb	Partially sorted, un-accommodated	Single spaced enaulic, yellow SS	1/1
	4		25	2	15	2	5	1	t	1	t	SR	Grey + low IC	-	-	-	-	5	-	-	5	-	t	1	2	10	5	2	t	t	t	5	30	Weak pedality, crumb	Partially accommodated, unsorted	Close fine enaulic, grey SS	2/1
	5		25	3	10	2	5	1	2	1	-	SR	Grey + low IC	1	1	-	-	10	5	150 x 50	-	-	-	-	5	t	5	5	t	t	30	10	30	Moderate pedality, crumb	Partially accommodated, unsorted	Single spaced enaulic, grey-yellow SS	2/1
5A	1	O	20	2	15	2	2	1	-	-	-	SR	Grey + low IC	-	-	-	-	10	5	100 x 50	t	-	t	2	5	10	5	t	-	-	-	5	20	Weak pedality, granular	Partially sorted & well accommodated	Single spaced porphyric, grey SS	2/1

Note: Micro stratum 1 of slide 5A has been identified as containing a deposit of reindeer faecal material (15% of stratum)

			Coarse mineral material (>10µm)															Coarse Organic material (>10µm)								Fine Organic Material (<10µm)				Pedofeatures				Structure			
Profile	Micro-strata	Depth (cm)	Quartz %	Quartz maximum size	Feldspar %	Feldspar maximum size	Siltstone %	Siltstone maximum size	Mica %	Mica maximum size	Glauconite %	Arrangement of minerals	Fine mineral material (<60µm)	Silt coating frequency	Silt coating maximum size	Organic carbon coatings frequency	Organic carbon coating maximum	Organ residue	Tissue residue	Largest tissue residue (mm)	Lignified tissue	Sclerotia	% Charcoal	Largest charcoal	Cell residue	Amorphous black	Amorphous yellow	Amorphous brown	Amorphous red	Excremental (*Spheroidal*) 50-100µm	Fe impregnated mineral material %	Fe impregnated organic material %	% void space	Microstructure	Course material arrangement	Groundmass b fabric	C/F ratio
	2		20	2	5	2	5	1	t	1	-	SR	Grey + low IC	-	-	-	-	5	2	100 x 50	10	-	20	5	2	10	2	t	-	-	t	5	15	Weak pedality, crumb	Partially sorted & well accommodated	Single spaced porphyric, grey SS	2/1
	3		20	2	10	2	10	2	t	1	-	SR	Grey + low IC	-	-	-	-	10	5	50 x 50	-	-	-	-	10	5	5	5	-	-	5	5	20	Moderate pedality, lenticular	Partially sorted & well accommodated	Double spaced porphyric, grey SS	1/2
	4		15	2	5	1	2	1	t	1	-	SR	Grey + low IC	2	4	-	-	5	10	50 x 200	t	-	-	-	10	5	5	10	2	-	25	10	30	Well-developed pedality, crumb	Well sorted & partially accommodated	Single spaced enaulic, brown stipple speckled	2/1
	5		25	3	5	2	2	1	t	1	-	SR	Grey + low IC	3	5	-	-	5	10	50 x 100	-	-	-	-	10	t	5	10	t	-	30	10	25	Well-developed pedality, crumb	Partially sorted & accommodated	Single spaced enaulic, yellow SS	1/2

4.3.5 Chemical analysis

4.3.5.1 pH

The pH values for the site have been graphed in figure 4.31 and repeat the same pattern of decreasing acidity with depth as seen in the podzolic profile at Prästsjödiket (profile 3). This pattern is seen across all three of the multi sampled profiles and demonstrates how on-going podsolization processes can alter the acidity of the soil profile. Even with this decrease in acidity with depth the levels remain acidic throughout ranging from just under 3.5 in profiles 1, 2 and 5 to just over a value of 4 (see figure 4.43).

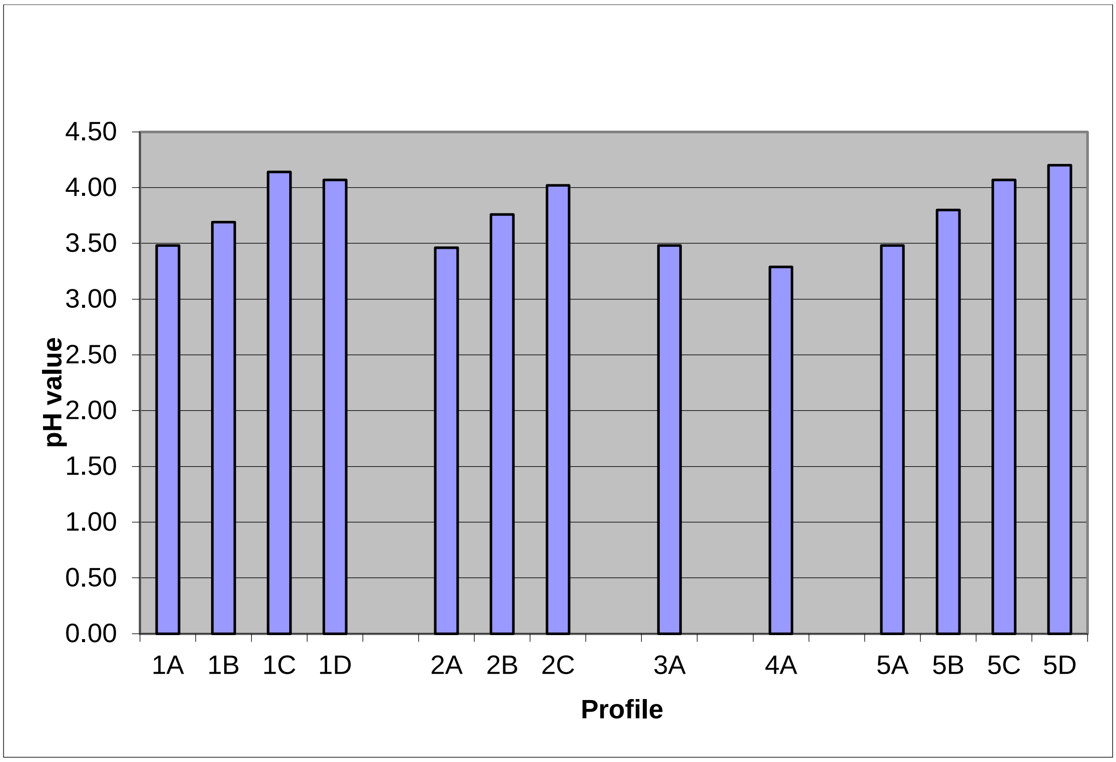


Figure 4.43: pH values for all profiles at Lass Mass Heden

4.3.5.2 Magnetic susceptibility

The mass specific magnetic susceptibility values for the five profiles at Lass Mass Heden shows several smaller peaks (profiles 1 and 2) with a larger peak in the topsoil of profile 5; see figure 4.44. The peak in sample 5A fits with a charred horizon in the related thin section slide (5A), which has a charcoal content of 20% in micro-strata 2; the geology is the same throughout all of the sites, therefore peaks can be attributed to burning activity rather than changes in mineralogy. As with Prästsjödiket the peaks in the magnetic susceptibility can be linked to the inclusion of charcoal within the thin section slides indicating burning activity. As there is no evidence of disturbance within the thin section slides the burning activity has been deemed as natural.

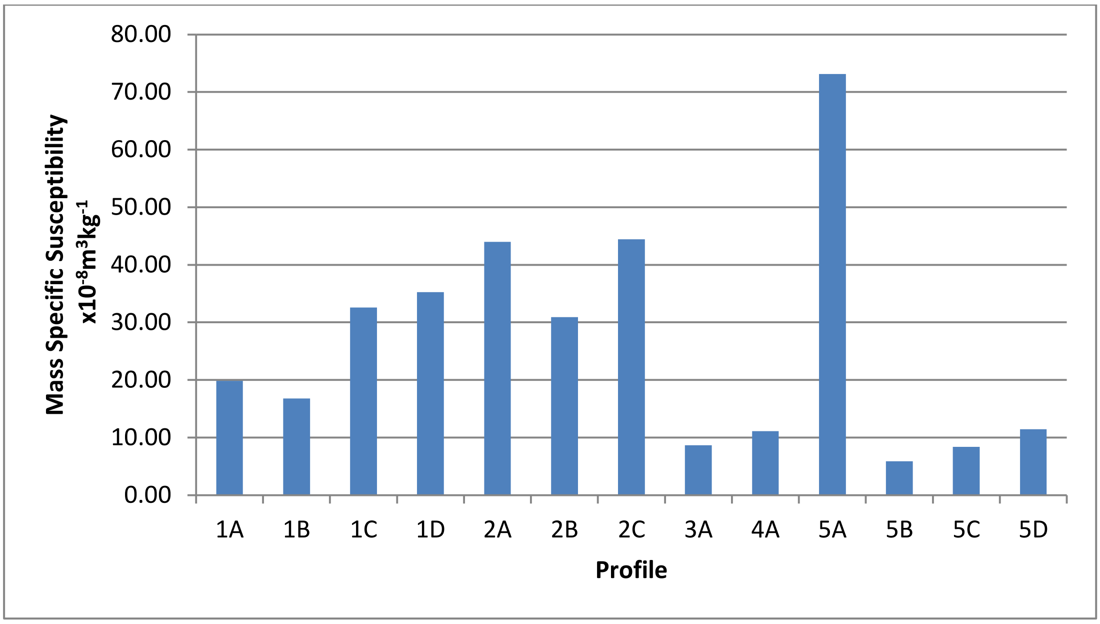


Figure 4.44: Mass Specific Magnetic Susceptibility values for Lass Mass Heden

4.3.5.3 SEM analysis

One way analysis of variance (ANOVA) was carried out on the grouped data for all horizons with the only significant relationship being with the chloride level; it was significantly different from those at Prästsjödiket and Tjärdal. Due to the crude nature of the grouped data further one way ANOVA's were carried out for each soil horizon. There were no significant relationships from the A horizon samples (see appendixes) but significant relationships between the phosphorous and chloride levels in the B horizons at Lass Mass Heden compared to Tjärdal were visible, see figures 4.45 and 4.46; European samples were added to the analysis so that minimum number of samples for analysis was reached as no B horizon present at Prästsjödiket, full results are available in appendixes. The difference in chloride levels is a reflection of the coarse analysis however the difference in phosphorous levels is very interesting. Since there is no evidence of cultivation from the field and micromorphological analysis the difference in phosphorous levels could be indicative of animal husbandry.

```
Source  DF        SS        MS     F      P
Site     5  0.013584  0.002717  6.04  0.001
Error   21  0.009446  0.000450
Total   26  0.023030

S = 0.02121   R-Sq = 58.98%   R-Sq(adj) = 49.22%

                     Individual 95% CIs For Mean Based on
                            Pooled StDev for Phosphorus levels
Level          N     Mean    StDev -------+---------+---------+---------+-
Lass Mass Heden 8  0.06375  0.02504                           (-----*------)
Tjärdal         2  0.02000  0.02828     (-----------*-----------)
                                   -------+---------+---------+---------+-
                                        0.000     0.025     0.050     0.075
```

Figure 4.45: Output from Tukey's multiple comparisons regarding the Phosphorous levels in the A horizons at Lass Mass Heden and Tjärdal

```
Source  DF        SS        MS     F      P
Site     5  0.017904  0.003581  4.96  0.004
Error   21  0.015163  0.000722
Total   26  0.033067

S = 0.02687   R-Sq = 54.15%   R-Sq(adj) = 43.23%

Individual 95% CIs For Mean Based on Pooled StDev
Level             N     Mean    StDev     -+---------+---------+---------+----
Lass Mass Heden   8  0.06375  0.04373                              (----*-----)
Tjärdal           2  0.00000  0.00000     (----------*----------)
                                          -+---------+---------+---------+---
                                        -0.035     0.000     0.035     0.070
```

Figure 4.46: Output from Tukey's multiple comparisons regarding the Chloride levels in the A horizons at Lass Mass Heden and Tjärdal

The analysis of the E horizon samples showed a significant difference in the aluminium levels across the three sites, particularly between Prästsjödiket and Tjärdal (see figure 4.47). The difference in the aluminium levels is most likely related to the difference in the level of soil formation as noted in the field evidence where the profiles at Prästsjödiket are a mixture of organic accumulations, gleys and weakly developed podzols whereas the podzols in the other two Sámi sites are visibly well developed.

The difference in the phosphorous levels seen in the A horizon is replicated within the E horizon (see figure 4.48) which is to be expected from the on-going podzolic processes evident in the soil. As there are E horizon samples from Prästsjödiket the difference in the P levels within the three Sámi sites can be identified as lying with Lass Mass Heden. This is of particular importance as possible reindeer excrement was identified in the thin section slides from profile 1 at Lass Mass Heden, indicating that reindeer have been kept on site. The difference in chloride levels seen in the A horizon is again repeated in the E horizon (see figure 4.49). This difference could be related to chemical changes within the soil as a result of the burning episode or could be an indication of proximity to the ocean or the use of marine materials on site as chloride ions are associated with salt, usually marine salts (Zahn and Grim 1993), however it could also be related to natural humification of organic material (Keppler and Biester, 2003). This would make for a very interesting future case study where controlled anthropogenic activities could be carried out in order to establish which, if any, significantly altered the chloride level in topsoil i.e. the volume of marine material required to increase the chlorine component of a natural topsoil's, if intense burning of biomass at Sámi hearths can cause localised raising of chloride levels in the surrounding topsoil and/or if burning of any sort can chemically alter the presence and availability of chlorine within the topsoil. However due to the volume of organic matter in the organic horizon and the eluviation processes it is likely that the peak is a result of the decomposing organic material.

```
Source  DF     SS     MS     F      P
Site     6  3.102  0.517  3.62  0.007
Error   34  4.853  0.143
Total   40  7.955

S = 0.3778   R-Sq = 39.00%   R-Sq(adj) = 28.23%

                           Individual 95% CIs For Mean Based on
                           Pooled StDev
Level            N    Mean   StDev  --------+---------+---------+---------+-
Prästsjödiket   11  1.6955  0.4388                    (----*----)
Lass Mass Heden  7  1.5000  0.3254               (-----*-----)
Tjärdal          5  0.9440  0.4158    (------*------)
                                    --------+---------+---------+---------+-
```

Figure 4.47: Output from Tukey's multiple comparisons regarding the Aluminium levels in the E horizons at Prästsjödiket, Lass Mass Heden and Tjärdal

```
Source  DF        SS        MS     F      P
Site     6  0.015431  0.002572  8.00  0.000
Error   34  0.010930  0.000321
Total   40  0.026361

S = 0.01793   R-Sq = 58.54%   R-Sq(adj) = 51.22%

                             Individual 95% CIs For Mean Based on
                             Pooled StDev
Level            N     Mean    StDev  --------+---------+---------+---------+
Prästsjödiket   11  0.02091  0.02119              (---*----)
Lass Mass Heden 7   0.06143  0.02478                               (-----*----)
Tjärdal          5  0.01400  0.01673         (------*-----)
                                      --------+---------+---------+---------+
                                            0.000     0.025     0.050
```

Figure 4.48: Output from Tukey's multiple comparisons regarding the Phosphorous levels in the E horizons at Prästsjödiket, Lass Mass Heden and Tjärdal

```
Source  DF        SS        MS     F      P
Site     6  0.016777  0.002796  8.10  0.000
Error   34  0.011736  0.000345
Total   40  0.028512

S = 0.01858   R-Sq = 58.84%   R-Sq(adj) = 51.58%

                             Individual 95% CIs For Mean Based on Pooled StDev
Level            N     Mean    StDev  ---------+---------+---------+---------+
Prästsjödiket   11  0.01455  0.01293            (----*---)
Lass Mass Heden 7   0.05714  0.03302                              (-----*-----)
Tjärdal          5  0.01600  0.01140           (-----*------)
                                      ---------+---------+---------+---------+
                                             0.000     0.025     0.050
```

Figure 4.49: Output from Tukey's multiple comparisons regarding the Chloride levels in the E horizons at Prästsjödiket, Lass Mass Heden and Tjärdal

4.3.6 Summary

Overall Lass Mass Heden appears to be an undisturbed podzol based site which has experienced several naturally induced burning events. What separates the site from Prästsjödiket is the strong evidence of reindeer husbandry which is evidenced through the inclusion of reindeer faecal material within the thin section slides and supported by a statistically significant peak in phosphorous throughout the soil profile. The difference in the chloride levels has been connected to the high level of organic matter in the upper soil horizon and the on-going eluviation process however this is an area that could be further investigated in future work.

The magnetic susceptibility peaks visibly fit with the high charcoal counts in the corresponding micromorphology descriptions, indicating that magnetic susceptibility is a reliable indicator of past burning activity. However due to the high frequency of naturally occurring forest fires any peaks that are not accompanied by subsequent human disturbance characteristics cannot be used as cultural indicators.

Lass Mass Heden had statistically higher phosphorous level in comparison to the other Sámi sites; throughout the A, O and E horizons. This has been successfully linked to historic anthropogenic activity, with the significant phosphorous levels supporting the inclusion of reindeer faecal material in the thin section slide from profile 1 at the site. This means that the P value and inclusion of reindeer faecal material at Sámi sites can be used as an indicator of past Sámi activity in the form of reindeer herding.

4.4 Tjärdal

4.4.1 Background

There are no historical records relating to Tjärdal, a common expectance with historic Sámi occupation sites. The visible hearth stones on site are the only indication of past Sámi occupation. Tjärdal has however been mapped as having acid to intermediate intrusive rock and podzol soil (Swedish Geological Society, 2010).

4.4.2 Study locations

The Tjärdal site is located next to a lake with a contemporary vegetation cover of birch trees with a higher level of moss and lichens than in Prästsjödiket. It is also more open and flatter than the other Sámi sites. Figure 4.50 shows a photograph of the current vegetation cover and landscape on site, figure 4.51 shows a typical podzol profile from the site (profile 1 in this instance) and the locations of the soil profiles have been mapped in figure 4.52 with an accompanying satellite image being shown in figure 4.53.

Figure 4.50: Photograph of Tjärdal showing 'typical' view

Figure 4.51: Photograph of profile 1

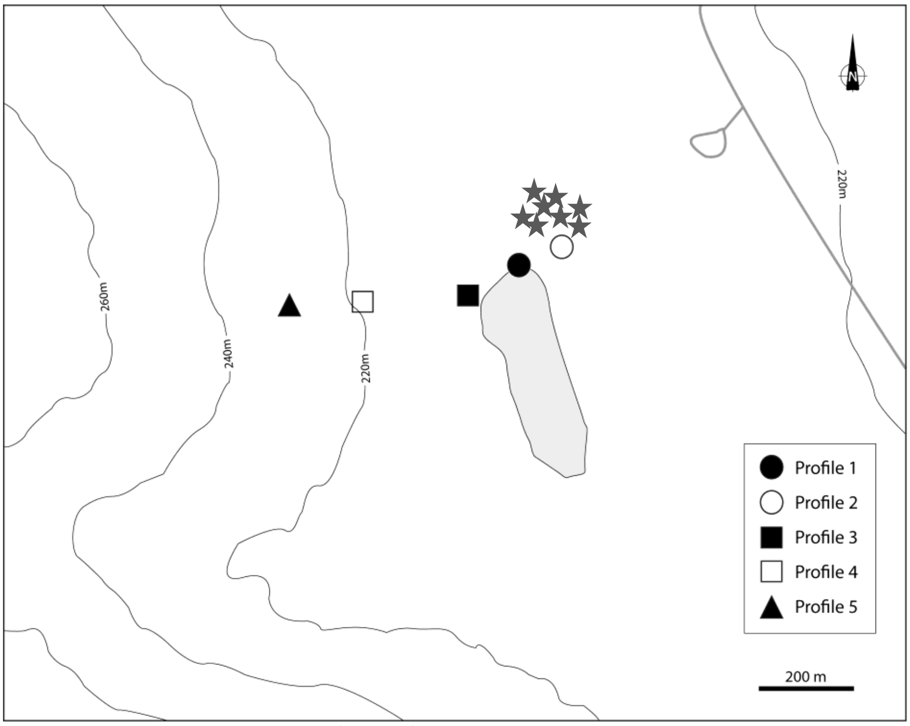


Figure 4.52: Map showing location of all profiles within the Tjärdal site; heart stones indicted by star

Figure 4.53: Screen grab of the Google satellite image showing profile locations (Google Maps, 2013)

Profile 1 is a podzol soil but is much less developed than in previous sites i.e. the E-horizon is much shallower; see figure 4.39 for photograph of profile. This is possibly due to either there being a higher input of nutrients to the soil in the form of animal dung either naturally or by man, or if the top layers of turf were stripped for construction purposes and/or burning. It has developed from fluvio-glacial sands with slight bands of different sized sand grains/stone appearing throughout indicating that the melt water had different levels of intensity.

Profile 2 is another very weak and thin podzol however it appears to be pinker in tone possibly indicating a higher level of iron in the soil. This profile also contained a higher concentration of stones, especially towards the bottom of the profile.

Profile 3 was another shallow podzol soil overlying fluvio-glacial sands and due to its stony nature required the Kubïena samples to be taken landscape instead of portrait.

Profiles 4 and 5 formed from a different material than the previous profiles; forming on bedrock. This profile was also in an area with a very high percentage of birch trees when compared to pine and formed a much deeper podzol. There were no fluvio-glacial sands present in this profile, only large boulders.

Profile 5 was back in an area with more pine trees than birch and was again a more developed podzol than in profiles 1 to 3. The horizon depths were irregular with the widths of each varying from the left to the right of the profile face. The profile was very shallow and appeared to be just off of the bedrock and was rich in very angular stones, which led to the Kubïena samples being taken from another face within the profile.

Overall, the field evidence has not unearthed any clear signs of occupation and/or disturbance other than the abandoned hearth stones. The possibility of turf removal at Tjärdal (profile 1) and the current difference in vegetation cover in comparison to the other two Sámi sites may be an indicator of past anthropogenic use/disturbance in that the turf has been stripped and vegetation cover is more open. However, it may also be related to a variety of natural factors so at this stage it cannot be earmarked as an indicator of past Sámi activity.

4.4.3 Chronology

Four samples were selected for dating from Tjärdal, three from profile 1 and one from profile 4. The full dating information and radiocarbon plot are presented in table 4.5 and figure 4.42 respectively; see figures 4.55 and 4.60 for the profile drawings showing the location of the samples within the soil profile. Samples B and D were both taken at a depth of 14cm from the top of the profile and returned overlapping, very early dates of BC1955-1760 and BC2195-1965 respectively. However sample A, taken at a depth of 1cm, returned a date of AD1489-1650, which just pre-dates the settlement of Europeans in the area. Although the proximity of sample A is close to the surface a natural podzol will have a slow accumulation rate indicating that, although still subject to the usual dating problems of wood and soil, that any disturbance or anthropogenic indicators present in the topsoil will have occurred within the possible cultural interaction/overlap phase. 4A, taken at a depth of 6cm, returned another early date of AD144-384, which overall suggests a very stable and undisturbed environment.

Table 4.5: Table containing information on location, type and age of all radiocarbon dated material from Tjärdal

Site reference	Sample reference	Depth of sample (cm)	Lab codes	Material	Radiocarbon Age BP	Calibrated Date (≥95.4%)
Tjärdal	Sample 1A	1	26876 (GU20374)	cf Betula	305±30	AD 1489-1650
Tjärdal	Sample 1B	14	26877 (GU20375)	cf Salix	3540±30	BC 1955-1760
Tjärdal	Sample 1D	14	26881 (GU20376)	Coniferales	3685±30	BC 2195-1965
Tjärdal	Sample 4A	6	26882 (GU20377)	Pinus sylvestris	1760±30	AD 144-384

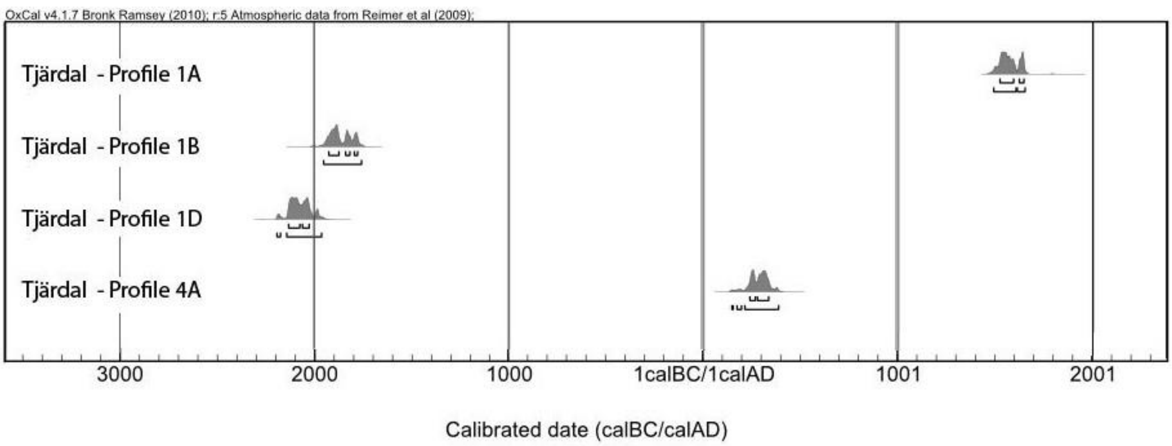


Figure 4.54: Radiocarbon plots showing the calibrated dates for the three samples dated from Tjärdal

4.4.4 Micromorphology

4.4.4.1 Profile 1

4.4.4.1.1 Description

Sample 1B was captured at a depth of 17cm, and is a continuation of the B-horizon seen at the lower end of slide 1A, (see figure 4.55 for soil profile drawing and location of the sample). It has a single grain microstructure with the very few periglacial silt. The iron accumulations and levels of organic material have also decreased from the B-horizon material in slide 1A, which is to be expected with the increased depth.

Slide 1A was taken at a depth of 0cm and contains 3 micro-strata, which from bottom to top are a B-horizon followed by a poorly developed E-horizon and a thin charred micro-stratum.

The B-horizon is iron stained as expected (15% of mineral material) but with an unusually high level of organic material present (30% of area). This includes a trace of spheroidal excremental material in addition to common organic coatings on the mineral grains of up to a size 2 category. Silt coatings are present but are of a size 1 category and very rare.

The E-horizon is weakly developed, as indicated by the weakly developed crumb microstructure and iron stained (30%) mineral material. There are rare organic coatings present up to a size 1 category.

The upper charred stratum is natural in origin and has the same characteristics as the E-horizon material as seen in the previous sites. Organic coatings on the minerals are more common in this stratum than in the underlying E and B-horizons which may be related to the fractured nature of the charcoal; present up to size category 2. The un-charred organic materials present are fresher, i.e. contain more parenchymatic tissue, than in the underlying strata.

4.4.4.1.2 Interpretation

The occurrence of periglacial silt capping's and the single grain microstructure in the lower profile indicates that the mineral material may have been a glacial deposit. The inclusion of spheroidal excremental material within the B horizon is unusual but due to the undisturbed nature of the profiles structure and the soil's natural illuviation and alluviation processes, evident through the displaced micro-charcoal and subsequent organic carbon coatings, it indicates that the materials have been introduced by root growth.

The weakly developed crumb microstructure within the E-horizon indicates that the podzol is poorly developed. The inclusion of organic carbon coatings throughout the E and B-horizon however are evidence of the on-going illuviation and alluviation processes, indicating that the podzol soil is still forming.

The charred stratum directly overlies the E-horizon and, as seen at previous sites, is overlain by a substantial organic accumulation. This sequence of charred material directly above the E-horizon and overlain with a typically biologically active organic accumulation is the emerging picture of natural podzol soils within an undisturbed environment which is subject to frequently occurring forest fires. There is no evidence of disturbance or anthropogenic input throughout this profile.

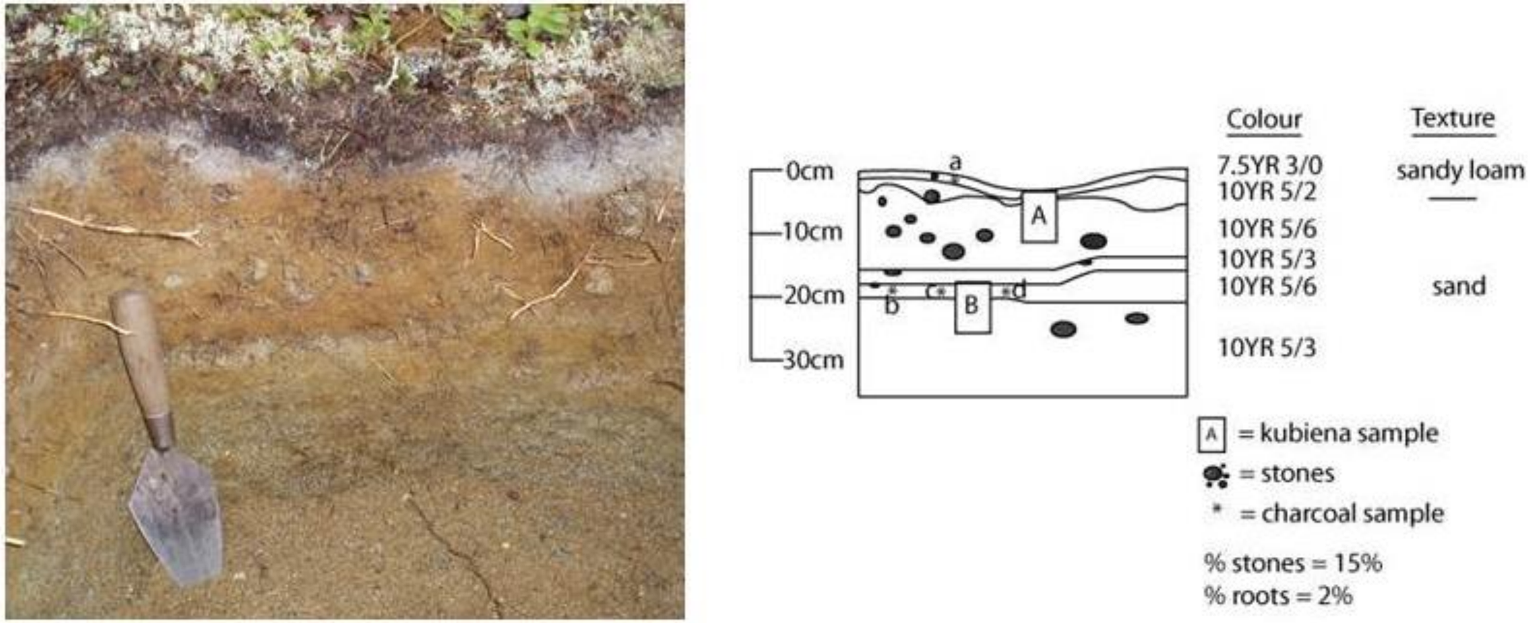


Figure 4.55: Photograph and soil profile diagram of profile 1

4.4.4.2 Profile 2

4.4.4.2.1 Description

Slide 2A was taken at a depth of 0cm and encompasses four micro-strata, which from the bottom to the top of the slide are the B-horizon, E-horizon, charred stratum and an organic stratum; see figure 4.56 for soil profile drawing and location of slide.

The B-horizon is iron stained (30% of mineral material) with an unusually high level of organic material present (20% of area) including a trace of spheroidal excremental material. There is however no organic carbon coatings present and very few periglacial silt coatings up to size band 2.

The contrast between the B and E horizon is visibly marked by the increased level of fine organo-mineral b-fabric material present, by a slight decrease in mineral grain size (please see table 4.6) and most distinctly by the significant change in iron stained mineral grains; a trace in the E-horizon and 30% in the B-horizon.

The E-horizon is more developed than that in profile 1 and only has a trace of iron stained minerals. Silt coatings up to size 1 are very rare with organic coatings present up to size 3 (very few).

The charred stratum directly overlies the E-horizon with smaller charcoal fragments having begun to migrate into the upper quarter of the E-horizon. The charcoal fragments are coarser than those seen in profile 1 (largest measured $4mm^2$) but as there is a higher quantity of them in this profile, 15% compared to 2% in profile 1, with organic coatings up to size 2 are common.

The charcoal stratum is directly overlain with an organic accumulation as is typical of the emerging forest fire pattern. The stratum is predominantly made up of amorphous organic material (35%) and excrementally reworked organic material (20%), see figures 4.57 and 4.58 for photographs, and contains 18 sclerotia spores.

There is another very thin band of charcoal presents in the upper right hand corner of the slide, which overlies the organic stratum just above where the majority of the sclerotia spores are visible. There is a trace of mineral material within the organic stratum indicating a low level of disturbance, which would support the theory of renewed interest and/or activity at this location.

4.4.4.2.2 Interpretation

The level and assortment of organic material within the B-horizon is very similar to that seen in the B-horizon of slide 1A which shows a consistency of podzol development across the site. This is of importance as it indicates a uniform development across the site, making any anthropogenic amendments to the soil more obvious.

As the silt coatings in the B-horizon are larger and more common than in profile 1, in addition to the high level of iron staining and moderately developed crumb pedality, the podzol appears to be more developed than profile 1. This may be related to several natural factors such as local differences in drainage patterns or in the underlying bedrock, but has no indication of anthropogenic influence.

The E-horizon of the podzol is still not fully developed, as signalled by the single grain microstructure. The rare occurrence of silt coatings within this stratum is to be expected due to the decreasing depth. As there is no indication of anthropogenic disturbance and evidence of on-going illuviation/alluviation processes the organic coatings (up to size 3) have been tied to the associated podzolisation processes of the soil.

The E-horizon is overlain with a charred stratum which indicates a burning event. There are a higher percentage of charcoal fragments, and they are coarser in size, present here than were present within profile 1. This indicates a difference in the vegetation burnt or the intensity of the fire i.e. vegetation here was bulkier in this profile, perhaps indicating that profile 1 was in an area with more open or sparser vegetation cover. The increased carbon coatings can also be related to the increased availability of carbon; from the micro-charcoal present.

As expected with the emerging organic accumulation triggered by a burning event there is an organic accumulation directly overlying the charred stratum. Interestingly the stratum has been subject to a high level of biological activity as indicated by the high percentage of excrementally reworked organic material, but the deposit also contains 18 sclerotia spores which are typically indicative of poor soil conditions; either waterlogging or poor fertility. As there has been no evidence to suggest waterlogging of the soil the sclerotia must indicate poor fertility, which is contradictive of the biological activity. It has therefore been suggested that due to the lack of parenchymatic tissue within the biologically reworked organic material, that the biological activity is historic and that the organic deposit has overtime become exhausted, leading to the inclusion of the sclerotia spores.

The final charcoal deposit is located in a linear lamination above the majority of the sclerotia spores. As the spores occur in an almost unbroken linear band, it is assumed that the particles of charcoal present have not been introduced from the lower stratum as a result of bioturbation, but from a second burning event. If anthropogenic in origin the burning event may have been carried out in order to stimulate further organic accumulations and therefore increase the fertility of the upper soil. There is a trace of mineral input which may indicate low level disturbance but due to the small size of the mineral grains and the limited volume present the inclusion of both the mineral material and charcoal has been deemed as naturally occurring; no evidence of anthropogenic amendment or disturbance is visible within the profile.

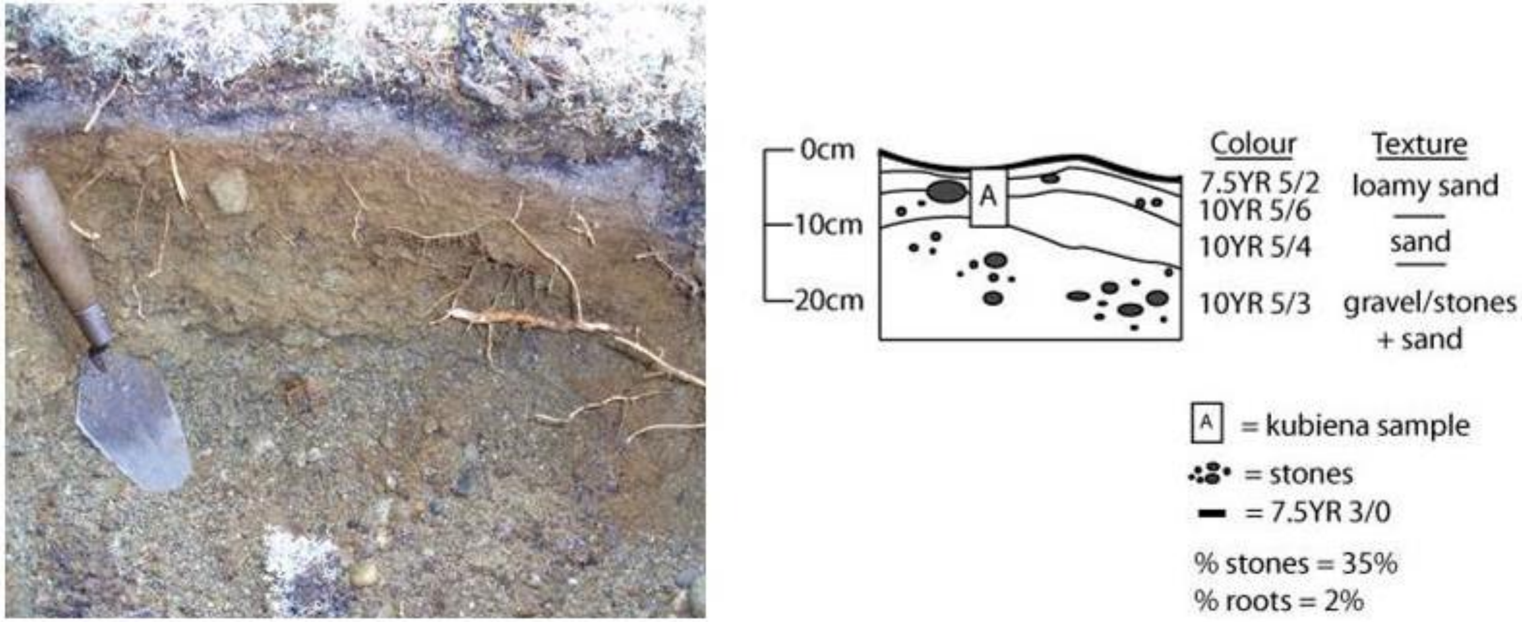


Figure 4.56: Photograph and soil profile diagram of profile 2

Figure 4.57: Mite excrements PPL x10 mag

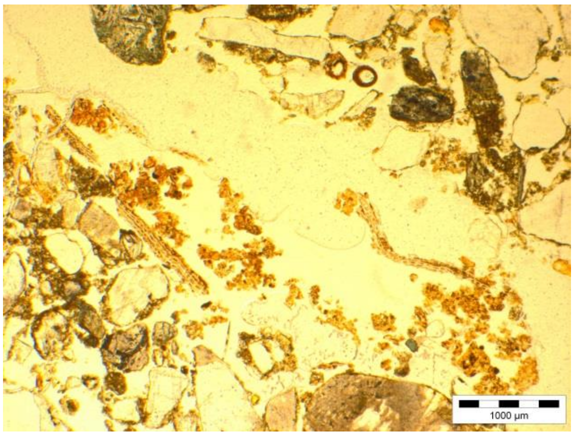


Figure 4.58: Mite excrements XPL x2 mag

4.4.4.3 Profile 3

4.4.4.3.1 Description

Slide 3A was taken horizontally at a depth of 0cm and encompasses four micro-strata which from the bottom to the top of the slide are the B-horizon, E-horizon, charred stratum and an organic stratum; see figure 4.59 for soil profile drawing and location of slide.

The B-horizon is iron stained as expected (20% of mineral material) with a much lower level of organic material present (12%) than seen in profiles 1 and 2 (30% and 20% respectively). The stratum does have a very high mineral percentage (62%) due to size of the minerals reaching level 5 (quartz). There is periglacial silt capping’s present up to size band 3 (very few).

The E-horizon has a high level of iron stained minerals (10%) and a weakly developed crumb microstructure. Organic coatings are rare and only reach size band 1.

The charred and organic strata have unclear boundaries from one another due to the disturbance from the large roots (20%), with the charcoal (10%) being difficult to differentiate from the lignified tissue (15%). Organic coatings are rare but up to size band 3.

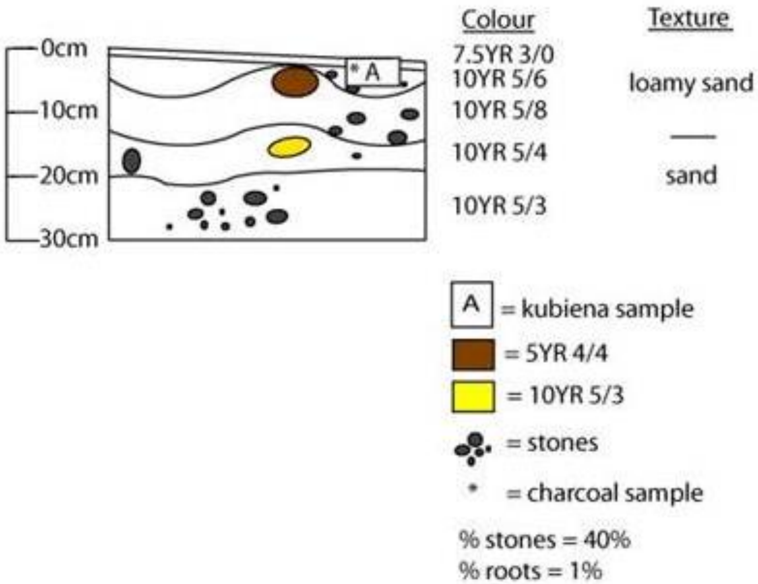


Figure 4.59: Photograph and soil profile diagram of profile 3

4.4.4.3.2 Interpretation

The large mineral grain size and accompanying silt capping's in the B-horizon is typical of the emerging B-horizon seen throughout the podzol soils sampled; it is present near the surface due to the shallow nature of this particular podzol.

The E-horizon is poorly developed, indicated by the high level of iron stained minerals (10%) and weakly developed crumb microstructure, and is similar to the E-horizon seen in profile 1. The organic coatings present are typical evidence of the natural illuviation and alluviation processes associated with podzol soils.

The E-horizon is overlain with charred and organic strata. Unusually the boundaries between the two are unclear but this profile has a higher percentage of roots which due to the shallow nature of the deposit will have disturbed the horizons resulting in the mixing evident between the two. The rare organic coatings are further evidence of the illuviation and alluviation process and the increased availability of carbon within the soil; from the charred material. Due to the profiles shallower nature, root disturbance and bioturbation has mixed the boundaries between the charred and organic strata but overall it fits with the undisturbed podzol soils seen across the site i.e. a podzol with a charred stratum overlying the E-horizon which has a triggered an organic accumulation.

4.4.4.4 Profile 4

4.4.4.4.1 Description

Slide 4B was taken at a depth of 6cm, to the left of slide 4A, and due to the undulating nature of the profile encompasses the same E and B-horizons that are contained in slide 4A; see figure 4.60 for soil profile drawing and location of slide.

The B-horizon is again organic rich (55%) and deeply iron stained (30%) as has been seen in other B-horizons at this site. The microstructure varies from a moderate to weakly developed crumb, size 2 organic coatings are common and there is a discreet lenticular microstructure in the lower right hand corner. The lower right hand corner of the slide is rich in organic material and is very homogenised in appearance and is slightly less iron stained than the rest of the stratum; see figures 4.61 and 4.62. Periglacial silt coatings are present up to size 3 (very few) in addition to sclerotia, and iron and manganese nodules; the nodules increase in size as the depth decreases.

The E-horizon contains several mycorrhizal mantles as in slide 4A but is high in organic material (37%) with a weakly developed granular microstructure with areas where the clay sized particles orientating themselves into the lenticular microstructure typical of E-horizons. Organic coatings are again common in this stratum (up to size 2).

Slide 4A was taken at a depth of 0cm and encompasses three micro-strata, which from the bottom to the top of the slide is the E/B horizon, charred stratum and an organic A horizon.

The E/B-horizon is a highly disturbed mix of both E and B horizon material with no clear segregation. The microstructure is poorly developed and iron accumulations vary widely across short distances from 0% to 30% and iron nodules. A single sclerotia spore is present alongside several mycorrhizal mantles present at the bottom of the slide; see figures 4.63 and 4.64 for photographs.

The charred stratum is charcoal rich (50% of stratum) with very large charcoal fragments (≥25x15mm).

As expected there is an organic accumulation above the charred stratum, which is biologically very active with 40% amorphous organic material, 5% excremental material and several mycorrhizal mantles present. There is a trace of quartz grains (<20μm) located evenly throughout the stratum. There are four sclerotia spores present in this stratum. There is also a single sclerotia present within the E/B horizon.

4.4.4.4.2 Interpretation

The discreet lenticular microstructure in the lower right of the B-horizon material is consistent with freeze thaw disturbance; the expansion and contraction of the freezing and thawing material develops linear laminations of fine material. There is an area of organic rich, homogenised microstructure within the lower right corner of the B-horizon which does not fit with the typical B-horizon material seen at other sites and profiles. The inclusion of the organo material this deep in the profile is indicative of historic mixing and/or disturbance as the material has been introduced deeper in the profile than it is traditionally found; most likely through bioturbation. The homogenisation is the result of the age of the material in that the organic fraction has decomposed, resulting in an amorphous rich, homogenised appearance. Iron and manganese nodules are present within the horizon and increase in size with decreasing depth. They indicate not only the age of the profile, as they have a long formation time, but also that they profile has suffered from waterlogging, which ties in with the sclerotia identified in slide 4A and invalidates any comparison to anthropogenic soil types.

The E-horizon is undisturbed with lenticular voids superimposed onto the weakly developed granular microstructure. The E-horizon boundary with the B-horizon is highly distorted. Due to the undulating morphology of the horizon boundaries and the emerging lenticular patterns within the microstructure this has been attributed to frost heave (freeze thaw action). There are several mycorrhizal mantles and a single sclerotia spore present but due to the disturbed nature of stratum it is difficult to identify whether they have formed in situ or have translocated. Due to the level of mixing between the E and B-horizons, it is possible that the mixing has occurred as recently as within the last 100 - 350 years, according to Mokma et al’s (2004) podzol formation times, as the strata have not yet rearranged themselves back into a typical podzol. It is also possible that these areas of mixed strata are natural and are self-correcting i.e. resettling/reforming podzols.

The E-horizon is, as expected, overlain with a charred stratum and subsequent organic accumulation. The charcoal fragments within the charred stratum and very large in size, indicating that they are from larger vegetation i.e. wood. The overlying organic accumulation contains a trace of quartz grains which due to their size and the equal nature in which they occur indicates that they were either aeolian deposited or introduced from the lower strata by micro faunal activity.

Given the size of the charcoal fragments, the pocket in which the charcoal has accumulated in, and the disturbed nature of the surrounding E/B horizon, but the lack of disturbance elsewhere in the site, it is most probable that this has been the result of a naturally occurring tree throw. As the wood material appears to have been burnt in situ it is possible that the tree went over during, and possibly as a result of, the burning episode. The inclusion of sclerotia spores within the organic accumulation, and the single spore within the E/B horizon, indicates a poor soil environment. This fits with the emerging sequence seen at the previous profiles in that a burning event encourages an organic accumulation, the organic accumulation is primarily biologically active but will eventually decrease in fertility/quality. As the inherent podzol soils are nutrient poor it is being suggested that the increased fertility resultant from the charring event is only temporary, and that the soil will revert to its natural state unless secondary burning events occur.

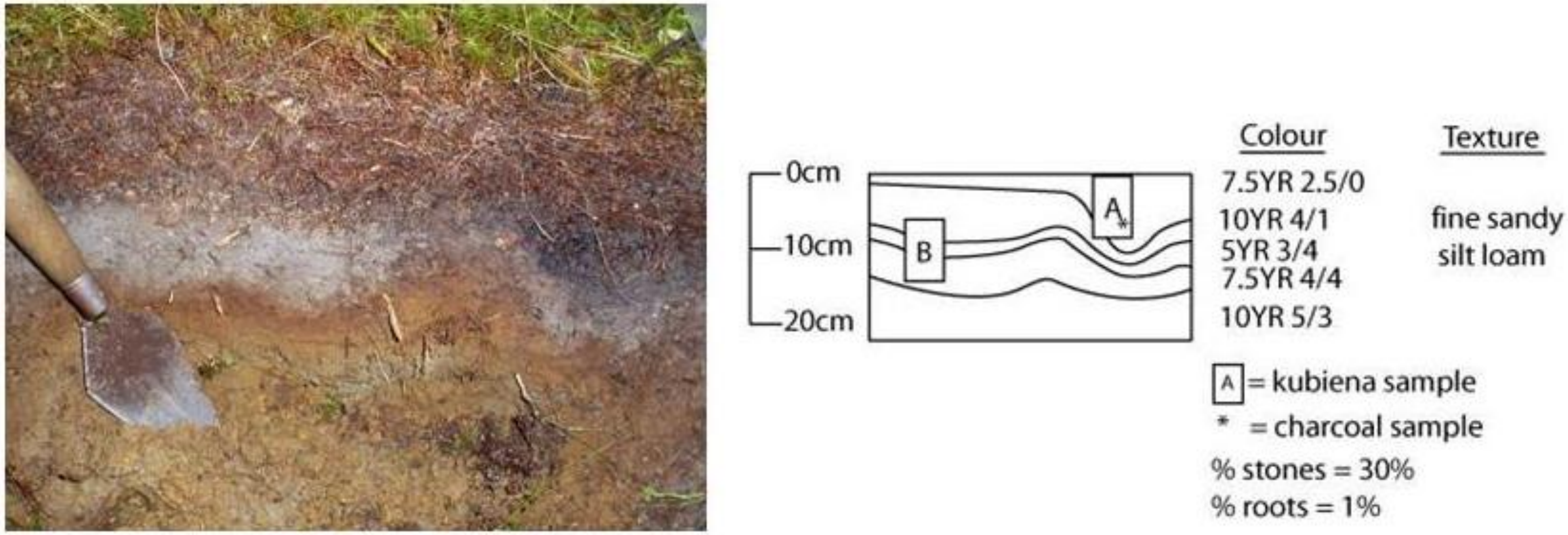


Figure 4.60: Photograph and soil profile diagram of profile 4

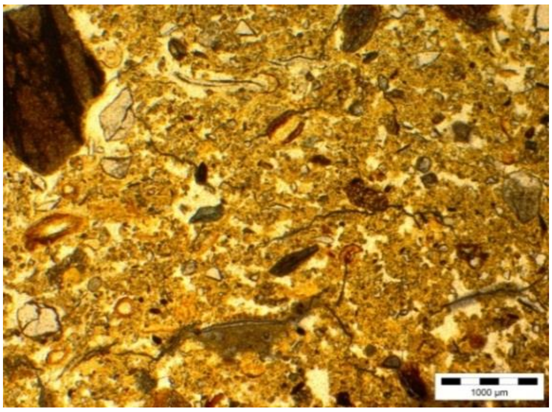


Figure 4.61: Homogenised microstructure in B horizon PPL x2 mag

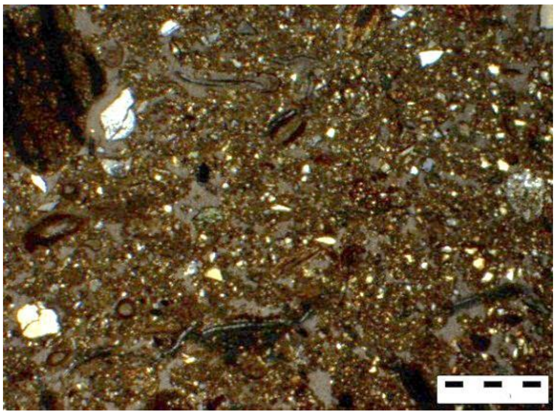


Figure 4.62: Homogenised microstructure in B horizon XPL x2 mag

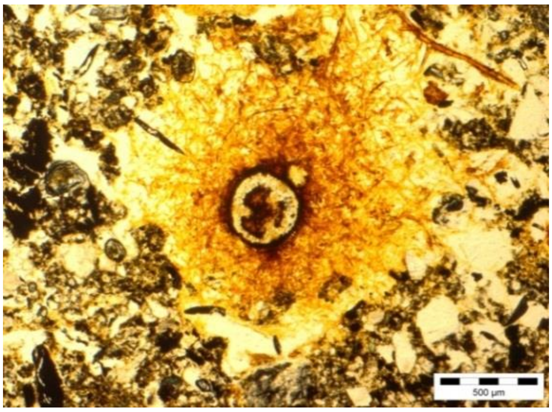


Figure 4.63 Mycorrhizal mantle PPL x4 mag

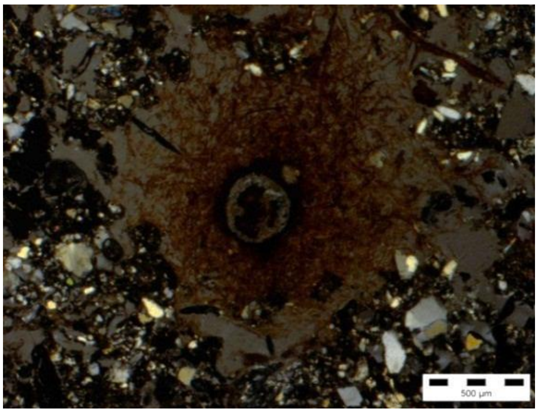


Figure 4.64: **Mycorrhizal mantle PPL x4 mag**

4.4.4.5 Profile 5

4.4.4.5.1 Description

Slide 5A was taken at a depth of 0cm and encompasses four micro-strata, which from the bottom to the top of the slide is the B-horizon, E-horizon, charred stratum and an organic stratum; see figure 6.65 for soil profile drawing and location of slide.

The B-horizon is iron stained as expected (20%) with 40% organic material, which is similar to the B-horizons seen in profiles 1 and 2 (30% and 20% respectively). It has a crumb microstructure with lenticular voids.

The E-horizon has a moderately developed lenticular microstructure and just a trace of iron stained minerals. The E-horizon is directly overlain by a thin lamination of black amorphous, organic material. This micro-stratum of amorphous material is then directly overlain by a deep accumulation of organic material.

This organic stratum contains micro laminations of different organic accumulations including several which fit with the size, fragmented nature and colour, both in PPL and XPL, of the organic material seen in the reindeer excrement control sample.

4.4.4.5.2 Interpretation

Even with the B-horizon displaying minor distortion from freeze thaw processes in the form of lenticular voids within its crumb microstructure it is a natural, well developed podzol. The E-horizon is the most developed out of the site as it has the most developed lenticular microstructure and lowest percentage of iron stained mineral grains (trace). The E-horizon is overlain with a black amorphous organic horizon which as the organic material is dark brown in colour and indicates that it is preserved, possibly ferruginised, matter rather than charred material. As the soil transect was taken in order starting at the settlement area and heading out into the hinterland, it is probable that the forest fires seen in the previous samples did not reach profile 5; profile 5 located up an embankment across a small stream, with surrounding bog, from the other profiles so it is feasible that this would have acted as a natural fire corridor preventing the spread of the forest fire seen in profiles 1-4 to the woodland across the stream and up the embankment where profile 5 is located.

This stratum is overlain with a deep organic accumulation which contains several micro laminations of fragmented organic material including reindeer faecal material. Although the faecal deposit is located at the profile furthest away from the settlement it is still in close proximity, indicating that reindeer husbandry was employed by the occupying Sámi. This indicates that evidence of reindeer husbandry is present at two out of the three Sámi sites studied.

4.4.4.6 Summary

Overall the micromorphology confirms the podzolic and infertile nature of the soils on site and shows no evidence of European style cultivation or clearance practises. The emerging response of organic accumulations after naturally induced burning episodes on podzol soils can be seen at all profiles in this site, excluding profile 5, which is segregated from the others by a natural fire corridor. Profile 5 contains reindeer faecal matter that is evidence of reindeer grazing activity. The faecal material could not be radiocarbon dated however the proximity of the material (profile 1) in relation to the hearth stones indicates that the reindeer were not afraid of the humans and/or that the reindeer were concentrated in this area for a purpose such as milking or to be kept in an enclosure. This indicates that the reindeer were domesticated which is a later phase of Sámi activity.

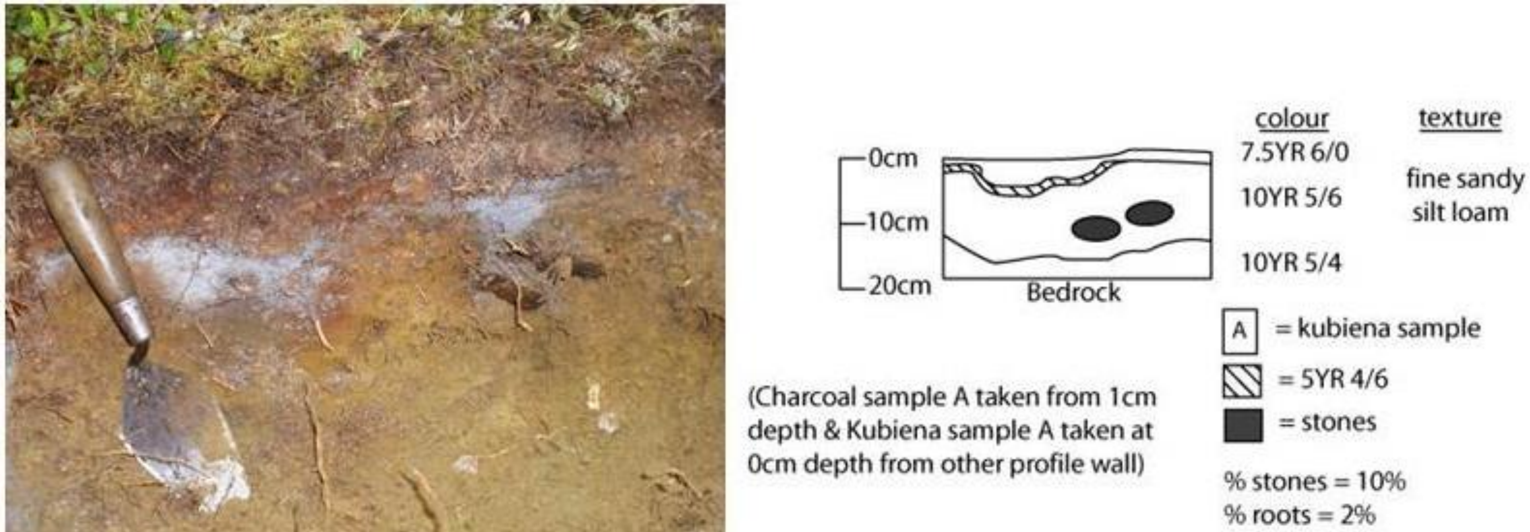


Figure 6.65: Photograph and soil profile diagram of profile 5

Table 4.6: Micromorphology description tables for Tjärdal slides

				Coarse mineral material (>10µm)														Coarse Organic material (>10µm)								Fine Organic Material (<10µm)				Pedofeatures				Structure			
Profile	Micro-strata	Depth (cm)	Quartz %	Quartz maximum size	Feldspar %	Feldspar maximum size	Siltstone %	Siltstone maximum size	Mica %	Mica maximum size	Glauconite %	Arrangement of minerals	Fine mineral material (<60µm)	Silt coating frequency	Silt coating maximum size	Organic carbon coatings frequency	Organic carbon coating maximum	Organ residue	Tissue residue	Largest tissue residue (mm)	Lignified tissue	Sclerotia	% Charcoal	Largest charcoal	Cell residue	Amorphous black	Amorphous yellow	Amorphous brown	Amorphous red	Excremental (*Spheroidal*) 50-100µm	Fe impregnated mineral material %	Fe impregnated organic material %	% void space	Microstructure	Course material arrangement	Groundmass b fabric	C/F ratio
1A	1	O	25	2	15	2	10	2	t	1	t	SR	Grey + low IC	-	-	2	3	10	T	50 x 50	-	-	2	2	t	t	t	t	-	-	15	5	40	Weak pedality, spongy	Partially sorted, un-accommodated	Single spaced enaulic, grey SS	3/1
	2		20	2	10	2	15	5	2	1	-	SR	Grey + low IC	-	-	1	2	5	10	300 x 50	-	-	-	-	10	5	5	t	-	-	30	5	15	Weak pedality, crumb	Partially sorted & well accommodated	Single spaced porphyric, brown SS	2/1
	3		20	5	10	4	10	1	2	1	t	SR	Grey + low IC	1	3	2	5	2	2	150 x 50	-	-	-	-	10	5	5	5	t	t	15	10	25	Weak pedality, crumb	Partially accommodated & sorted	Single spaced porphyric, yell-brown SS	2/1
1B	1	17	30	4	25	2	10	4	t	1	t	SA	Grey + low IC	1	2	-	-	2	3	50 x 25	t	-	2	5	t	t	t	t	t	t	10	t	30	V-weak ped single grain MS	Well sorted, un-accommodated	Convex gefuric, yell-brown SS	3/1
2A	1	O	t	1	t	1	-	-	-	-	-	SA	Grey + low IC	-	-	-	-	t	10	400 x 150	t	18	t	5	10	5	30	t	-	20	-	-	25	Very weak pedality, crumb	Partially accommodated & sorted	Close enaulic, yellow SS	2/1
	2		20	1	10	1	2	1	2	1	-	SR	Grey + low IC	-	-	2	5	-	-	-	5	-	15	6	t	15	t	t	t	-	-	-	30	Very weak pedality, crumb	Partially sorted & accommodated	Single spaced enaulic, grey SS	2/1
	3		30	2	20	2	15	2	t	1	t	SR	Grey + low IC	1	1	3	3	2	-	-	t	-	2	1	5	2	t	t	-	-	t	-	25	V-weak ped single grain MS	Unsorted & un-accommodated	Coarse monic, grey SS	5/1

				Coarse mineral material (>10µm)														Coarse Organic material (>10µm)								Fine Organic Material (<10µm)				Pedofeatures				Structure			
Profile	Micro-strata	Depth (cm)	Quartz %	Quartz maximum size	Feldspar %	Feldspar maximum size	Siltstone %	Siltstone maximum size	Mica %	Mica maximum size	Glauconite %	Arrangement of minerals	Fine mineral material (<60µm)	Silt coating frequency	Silt coating maximum size	Organic carbon coatings frequency	Organic carbon coating maximum	Organ residue	Tissue residue	Largest tissue residue (mm)	Lignified tissue	Sclerotia	% Charcoal	Largest charcoal	Cell residue	Amorphous black	Amorphous yellow	Amorphous brown	Amorphous red	Excremental (*Spheroidal*) 50-100µm	Fe impregnated mineral material %	Fe impregnated organic material %	% void space	Microstructure	Course material arrangement	Groundmass b fabric	C/F ratio
	4		20	3	10	2	20	2	2	1	t	SR	Grey + low IC	2	3	-	-	5	-	-	-	-	-	-	10	t	5	t	-	t	30	5	25	Moderate pedality, crumb	Unsorted, partially accommodated	Close enaulic, yellow-brown SS	2/1
3A	1	O	t	1	-	-	-	-	-	-	-	SA	Grey + low IC	-	-	3	1	20	5	50 x 25	15	-	10	5	10	10	2	t	-	-	-	t	30	Weak pedality, crumb	Unsorted, well accommodated	Single spaced enaulic, un-differentiated B-fabric	2/1
	2		20	3	10	3	10	1	t	1	t	SR	Grey + low IC	-	-	1	2	10	5	25 x 25	-	-	t	2	5	10	2	t	-	t	10	5	20	Weak pedality, crumb	Partially sorted & accommodated	Single spaced enaulic, grey SS	3/1
	3		50	5	2	4	10	3	t	1	-	R	Grey + low IC	3	3	-	-	2	-	-	-	-	-	-	5	5	t	-	-	t	20	5	25	Weak pedality, crumb	Unsorted & partially accommodated	Double spaced enaulic, brown SS	5/1
4A	1	0	t	1	-	-	-	-	-	-	-	SA	Grey + low IC	-	-	-	-	10	5	25 x 25	t	4	-	-	10	10	10	10	10	5	-	-	25	Weak pedality, granular	Partially sorted & accommodated	Single spaced enaulic, un-differentiated B-fabric	2/1
	2		2	1	-	-	-	-	-	-	-	SR	Grey + low IC	-	-	-	-	5	-	-	-	-	50	6	10	10	5	t	5	-	-	t	20	Weak pedality, crumb	Partially sorted & accommodated	Single spaced enaulic, brown SS	5/1
	3		20	2	10	2	2	1	2	1	-	SR	Grey + low IC	-	-	-	-	5	t	25 x 25	5	1	t	2	20	10	5	t	t	-	30	5	20	Weak pedality, crumb	Partially sorted & accommodated	Single spaced enaulic, grey SS	1/1

				Coarse mineral material (>10µm)														Coarse Organic material (>10µm)								Fine Organic Material (<10µm)				Pedofeatures				Structure			
Profile	Micro-strata	Depth (cm)	Quartz %	Quartz maximum size	Feldspar %	Feldspar maximum size	Siltstone %	Siltstone maximum size	Mica %	Mica maximum size	Glauconite %	Arrangement of minerals	Fine mineral material (<60µm)	Silt coating frequency	Silt coating maximum size	Organic carbon coatings frequency	Organic carbon coating maximum	Organ residue	Tissue residue	Largest tissue residue (mm)	Lignified tissue	Sclerotia	% Charcoal	Largest charcoal	Cell residue	Amorphous black	Amorphous yellow	Amorphous brown	Amorphous red	Excremental (*Spheroidal*) 50-100µm	Fe impregnated mineral material %	Fe impregnated organic material %	% void space	Microstructure	Course material arrangement	Groundmass b fabric	C/F ratio
4B	1	6	30	2	2	1	t	1	t	1	-	SA	Grey + low IC	-	-	2	5	5	t	25 x 25	5	-	-	-	5	10	5	5	t	2	10	2	20	Weak pedality, granular	Well sorted + accommodated	Open porphyric, grey/brown SS	1/3
	2		20	2	2	2	2	1	t	1	-	SR	Grey + low IC	3	3	2	5	5	5	500 x 25	-	-	-	-	10	10	10	10	t	5	30	10	20	Weak pedality, crumb	Partially sorted + well accommodated	Double spaced porphyric, org-grey SS	1/1
5A	1	0	t	1	-	-	-	-	-	-	-	SR	Grey + low IC	-	-	-	-	10	10	100 x 25	-	-	-	-	40	2	2	2	t	10	-	-	30	V-weak pedality, crumb	Partially sorted, un-accommodated	Single spaced enaulic, un-differentiated B-fabric	2/1
	2		30	1	t	1	-	-	t	1	-	SR	Grey + low IC	-	-	-	-	5	t	25 x 25	20	-	-	-	t	20	5	t	-	-	-	-	20	V-weak pedality, crumb	Well sorted, partially accommodated	Close porphyric, grey SS	1/2
	3		25	2	10	1	10	1	t	1	-	SA	Grey + low IC	-	-	-	-	10	t	25 x 25	-	-	-	-	5	10	5	t	-	-	t	-	25	Moderate pedality, lenticular	Well sorted & partially sorted	Double spaced porphyric, brown-grey SS	1/2
	4		20	2	t	1	10	1	t	1	-	SA	Grey + low IC	-	-	3	1	10	10	50 x 25	-	-	-	-	5	10	5	t	-	-	20	10	25	Weak pedality, crumb	Well sorted & partially sorted	Double spaced porphyric, brown-grey SS	1/2

Note: traces of reindeer faecal material in stratums 1 +2, profile 5

4.4.5 Chemical analysis

4.4.5.1 pH

The pH values for the site repeat the emerging pattern of decreasing acidity with depth and are again very acidic with the pH values ranging from 3.6 to 4.2 (see figure 4.66). This acidity can be linked to both the podzolic nature of the soil but also to the tree cover; pine and spruce tree's are associated with, and known to increase, the acidity of forest soils (Alfredsson *et al*, 1998; Cunningham *et al*, 2001).

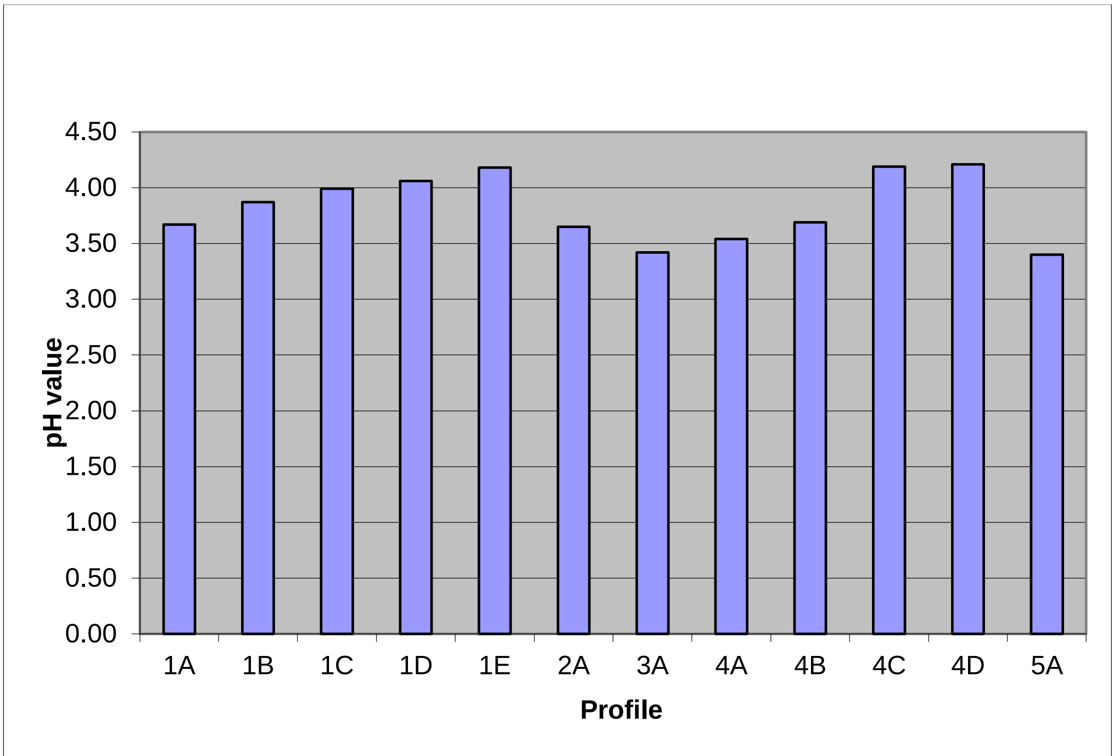


Figure 4.66: pH values for all profiles at Tjärdal

4.4.5.2 Magnetic susceptibility

Like with the other Sámi sites the mass specific magnetic susceptibility peaks visible in the bulk soil samples from Tjärdal samples fit with charcoal inclusions within the micromorphology descriptions (see figure 4.67). There does not appear to be any link between eluviation and the magnetic susceptibility values.

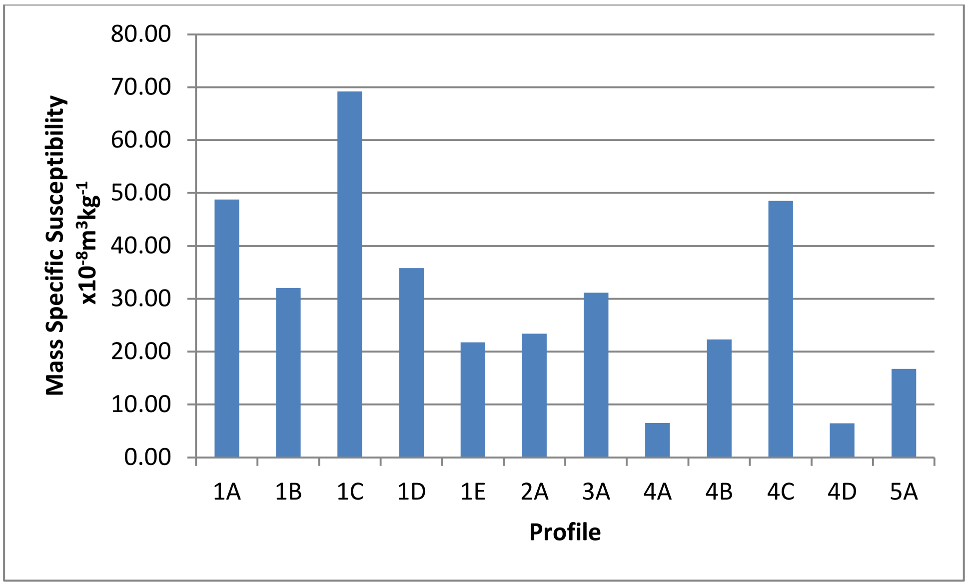


Figure 4.67: Mass Specific Magnetic Susceptibility values for Tjärdal

4.4.5.3 SEM analysis

The same statistical analysis used for the previous two sites was used for Tjardal's data but only one significant relationship emerged; no comparable samples available from Lass Mass Heden so the one way ANOVA was carried out using the European sets of data. A difference in chloride levels was evident throughout the profile Lass Mass Heden which suggests that the difference would also have occurred within the organic stratum if sufficient samples had been available (see figure 4.68). Overall it does indicate the need to further investigate the relationship between anthropogenic activities and chloride peaks through controlled environment experiments.

```
Source   DF        SS        MS     F      P
Site      6  0.026221  0.004370  5.57  0.001
Error    27  0.021179  0.000784
Total    33  0.047400

S = 0.02801   R-Sq = 55.32%   R-Sq(adj) = 45.39%

Individual 95% CIs For Mean Based on
                             Pooled StDev
Level          N     Mean    StDev  -----+---------+---------+---------+----
Prästsjödiket 11  0.03273  0.02936           (---*----)
Tjärdal        7  0.09143  0.01864                          (-----*----)
                                    -----+---------+---------+---------+----
                                       0.000     0.040     0.080     0.120
```

Figure 4.68: Output from Tukey's multiple comparisons regarding the Chloride levels in the O horizons at Prästsjödiket and Lass Mass Heden

4.4.6 Summary

The accumulation of mineral material at profile 4 which has buried past E-horizon and subsequent organic accumulation was attributed to erosion, indicating localised disturbance. However as this mineral accumulation has formed into a secondary albic horizon it sparks the question of whether the albic horizon is formed under accumulating organic material or does an albic horizon encourage the accumulation of organic material with or without a burning episode? The lower organic stratum had the same high level of biological activity seen at Lass Mass Heden which in the case of profile 3 appears to have exhausted itself before very limited local disturbance (increase in mineral content from a trace to 2%), indicating that organic accumulation is linked to the affect burning events have on the soil; a secondary burning event has then refreshed the organic accumulation and subsequent biological activity.

Overall this site fits well with the undisturbed landscape emerging from the analysis of the previous two sites. The podsolization processes are again visible through the translocation and partial dissolvent of the charcoal within the soil profile as well as through the chemical analysis. Encouragingly reindeer faecal material was again identified at profile 5. The associated phosphorous peak seen at Lass Mass

Heden is not evident here but as this could be related to the podsolization processes and/or the number of livestock kept, the inclusion of reindeer faecal material within thin section slides can be used as an indicator of Sámi activity.

The thin E-horizons at Tjärdal could indicate past turf cutting. Profile 1 exhibited a very thin E-horizon, which when teamed with the later radiocarbon date of AD1489-1650 from a charcoal sample taken at a depth of 1cm from the surface, indicates that any turf cutting occurred prior to this date i.e. before the influx of settling Europeans to the area and therefore was Sámi in origin and can be directly related to the surrounding Sámi hearth stones.

The mixed origin of the charcoal samples indicates that there has been an open mosaic of vegetation at the site that can be an indicator of anthropogenic activity; mosaic vegetation occurs through disturbance i.e. new vegetation introduced from seeds carried on clothing and/or trampling and selective clearing opening up the woodland and allowing pioneer and shrub species to grow.

Possible traces of reindeer faecal matter which were identified by comparison to a control sample of reindeer faecal matter collected on-site were present within profiles fives thin section slides however there was no significant P peak as seen in Lass Mass Heden. As the relationship between the reindeer faecal material and P values has been established in Lass Mass Heden the inclusion of faecal material without the P peak can be used as an indicator of Sámi occupation and past herding activity.

4.5 Synthesis

Although a clear picture of Sámi occupation, namely one of very low to almost no impact, has emerged from the individual analysis of the sites comparative analysis has also been carried out to supplement this understanding. The origin of the charcoal samples, patterns in the micromorphological coatings, and chemical comparisons between the sites have been used to identify any further key information.

4.5.1 Origin of charcoal samples

The origin of the materials dated is of interest as it could highlight differences in the surrounding vegetation of the site as well as highlight any foreign materials such as non-indigenous wood species which may have been introduced by trade. Figure 4.69 details the origins of the dated materials from the Tjärdal and Lass Mass Heden sites as material dated from Prästsjödiket was beetle fragments; the percentage weight has been calculated from the 9 samples dated (4 from Tjärdal and 5 from Lass Mass Heden) to make the data more representative. Of particular interest is the *Salix* present at the Tjärdal site as although the species is native to Sweden its osiers, rod like shoots, have long been used for weaving and its wood used for construction and could be a link to anthropogenic activity (Out 2009). Also, the mixture of sample origin at Tjärdal suggests a more mosaic vegetation cover, which is indicative of even slight anthropogenic impact (Regnell 2003); however as a more intense fire creates less charcoal it is also possible that the fire at Lass Mass Heden have been more intense, reducing all of the ground vegetation and shrubbery to micro-charcoal rather than visible pieces suitable for dating.

The varied origin of the charcoal fragments at Tjärdal could be down to natural variation but could also be indicative of anthropogenic disturbance within the vicinity via the opening up of the vegetation cover allowing for a more mosaic vegetation cover. Overall the radiocarbon dates support a natural and undisturbed environment, which has been subjected to natural forest fires; if anthropogenic in origin they have been caused accidentally rather than to prepare the area for cultivation.

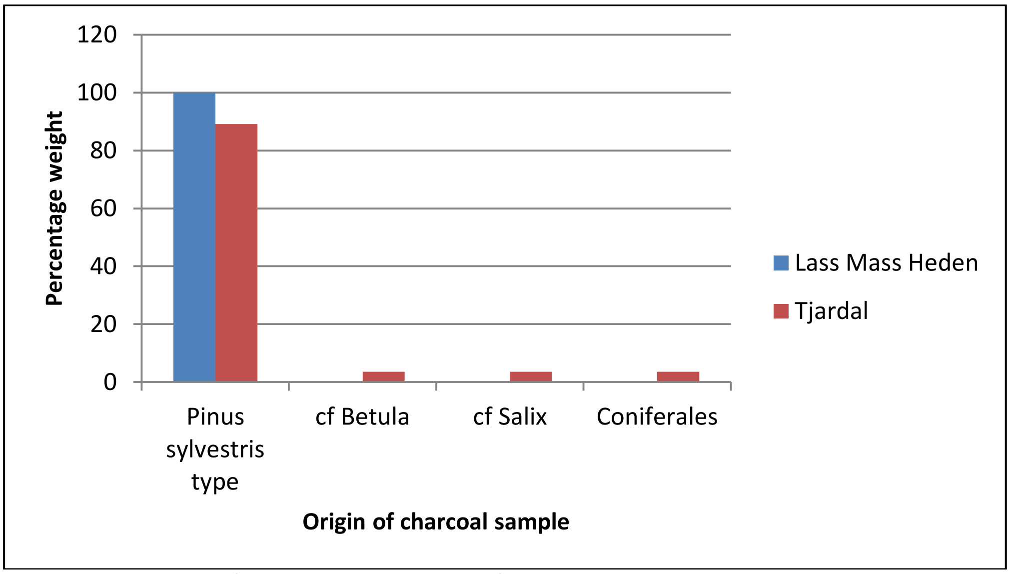


Figure 4.69: The origin of the charcoal samples dated from the Tjärdal & Lass Mass Heden sites

4.5.2 Coatings

The coatings observed in the micromorphology slides, both silt and carbon, are recorded in the description tables and discussed in the relevant micromorphology write up but have also been graphed so that any patterns or irregularities can be seen; there are not enough silt coatings for statistical analysis and statistical analysis of the carbon coatings did not return any significant results at a 95% confidence level. The coatings were recorded and measured according to size tables during the micromorphological analysis of the thin section slides and as not all slides contained either or types of coatings the sample numbers vary greatly from stratum to stratum and site to site; the key showing the equivalent percentages and sizes for the coatings is listed in table 4.7.

Table 4.7: Key for silt and carbon coating sizes and occurrence levels

Organic carbon coating size:	Occurrence levels:	Silt coating size:
<10µm = 1	Very rare (trace) = 1	<250µm = 1
10-25µm = 2	Rare (trace -2%) = 2	250-500µm = 2
25-40µm = 3	Very few (2-5%) = 3	500-750µm = 3
40-60µm = 4	Few (5-15%) = 4	750-1000µm = 4
60-80µm = 5	Common (15-30%) = 5	1000-2000µm = 5
>80µm = 6	Frequent (30-50%) = 6	>2000µm = 6

Figure 4.70 shows the silt and carbon coatings, size and occurrence, for all A-horizons and it is clear that silt coatings are rare within the A horizon and are only seen in profiles 1 & 3 at Lass Mass Heden. Carbon coatings are more common. The average carbon coating value for each Sámi site, in addition to the control samples, has been calculated and is shown in table 4.8. The carbon coating size is very consistent across the soil horizons, with a slight increase in size between the Sámi and control samples, and a peak at Prästsjödiket which was linked to the disturbance in the upper horizon evident in the micromorphology; the average values also peak within the E-horizon (see tables 4.8 – 4.10) supporting the podsolization processes seen in the micromorphology. However, two smaller silt coatings still occur within the Sámi profiles; both at Lass Mass Heden which due to the shallow nature of the profiles has been deemed natural (historic silt capping's close to surface due to shallow nature of soil. The higher occurrence and greater size of carbon coatings in the Sámi A-horizons in comparison to the control samples fits with the emerging pattern of increased levels and subsequent size of carbon coatings in and around charred strata in podzol soils; as discussed in the micromorphology sections. With the elevated occurence level at Prästsjödiket, profile 3A supporting the threshold value for anthropogenic impact argued earlier.

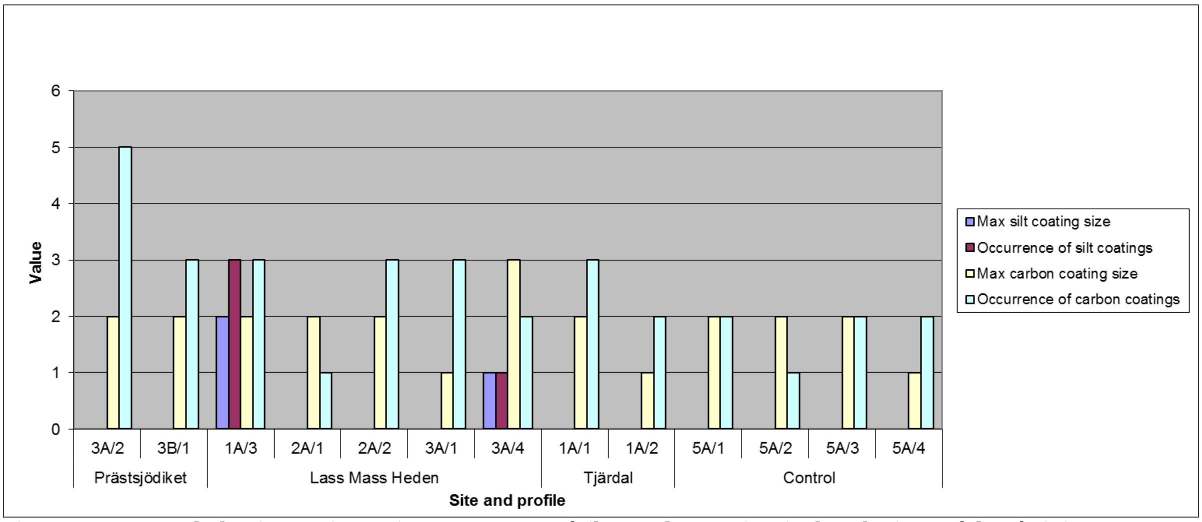


Figure 4.70 Bar graph showing maximum size & occurrence of silt & carbon coatings in the A horizons of the Sámi sites

Table 4.8: Averages of maximum size & occurrence of silt and carbon coatings in the A horizons of the Sámi sites and their corresponding control samples; averages are of the size and occurrence levels as per the key table (4.7)

	Max silt coating size	Occurrence of silt coatings	Max carbon coating size	Occurrence of carbon coatings
Average Sami:	0.3	0.4	2.1	2.8
Average control:	0.0	0.0	1.8	1.8

Figure 4.71 shows the silt and carbon coatings, size and occurrence, for all E horizons where again silt coatings are rare and only occur at an occurrence and size level of 1 at Tjärdal, profile 2A. There is more variation in the occurrence of carbon coatings with an average carbon coating size of 2.3 and an average occurrence of the carbon coatings of level 3 (see table 4.9). The values for the E-horizon are slightly higher from those seen in the A-horizon but this is to be expected as carbon material will have eluviated and been redeposited down profile of the source. The elevated occurrence of carbon coatings at Prästsjödiket again compliments the disturbance activity identified at the site. The occurrence and size values of the carbon coatings are lowest throughout Lass Mass Heden and again in profile 3A at Tjärdal, which is the furthermost profile from the occupation area and suggests a lower level of activity overall at Lass Mass Heden and a decreasing level of activity from the centre of occupation at Tjärdal which is to be expected.

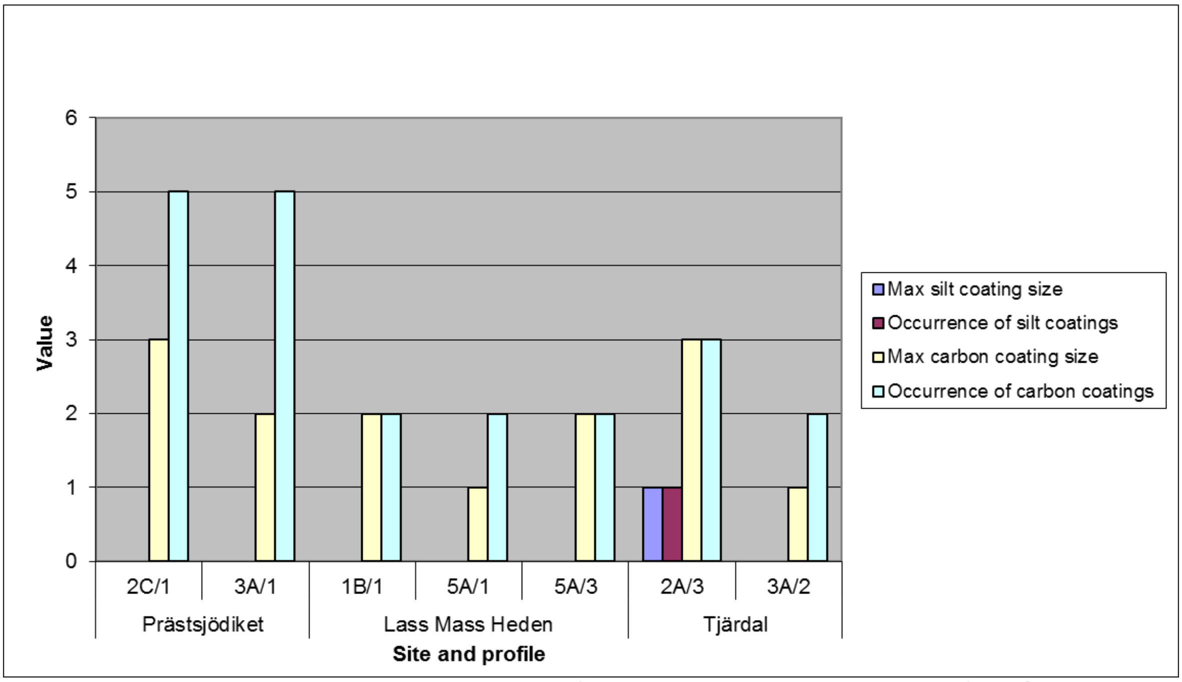


Figure 4.71: Bar graph showing maximum size & occurrence of silt & carbon coatings in the E horizons of the Sámi sites

Table 4.9: Averages of maximum size & occurrence of silt and carbon coatings in the E horizons of the Sámi sites and their corresponding control samples; averages are of the size and occurrence levels as per the key table (4.7)

	Max silt coating size	Occurrence of silt coatings	Max carbon coating size	Occurrence of carbon coatings
Average Sami:	0.1	0.1	2.3	3.0
Average control:	0.0	0.0	2.0	5.0

Figure 4.72 shows the silt and carbon coatings, size and occurrence, for all B-horizons where the level of silt coatings dominate for the first time. All average values are shown in table 4.10 where the average size of the silt coatings is slightly greater in the Sámi profiles, but the level of occurrence is greater in the control sites. However as this could be linked to the depth and subsequent age of the soil further assumptions about the Sámi choosing sites with superior climate conditions cannot be made. The increase in the occurrence and size of the silt coatings from very rare in the upper A and E horizons to common in the B-horizon is typical of a natural, undisturbed soil where the remnants of periglacial activity are situated in the lower horizons and occur less frequently towards the surface. The carbon coating size and frequency are of a lesser value than seen in the E-horizon which fits with the on-going podsolization processes.

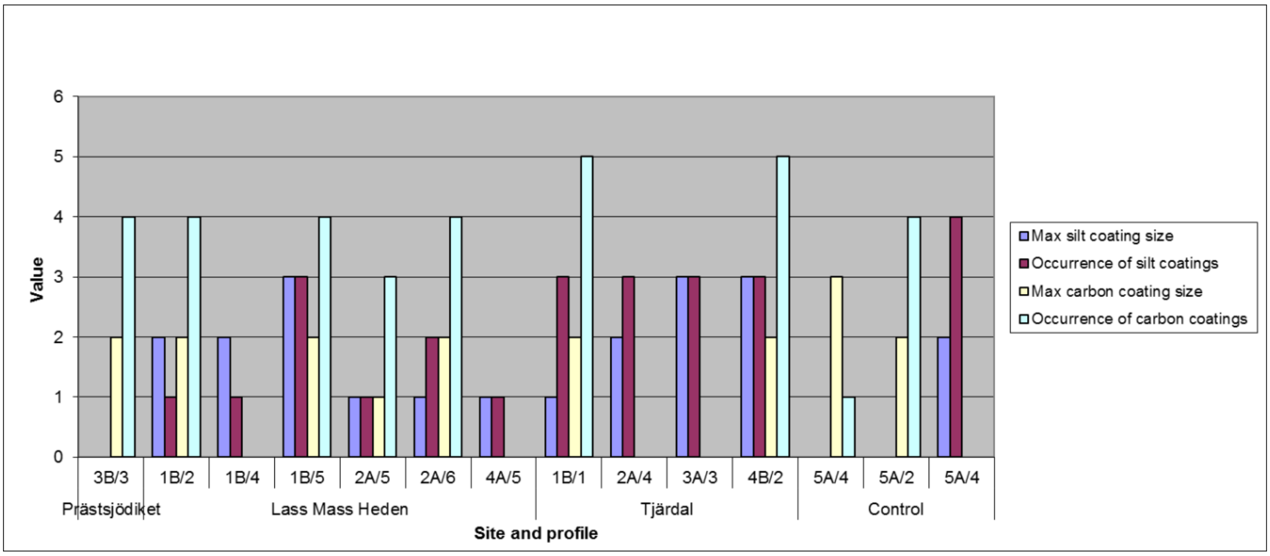


Figure 4.72: Bar graph showing maximum size & occurrence of silt & carbon coatings in the B horizons of the Sámi sites

Table 4.10: Averages of maximum size & occurrence of silt and carbon coatings in the B horizons of the Sámi sites and their corresponding control samples; averages are of the size and occurrence levels as per the key table (4.7)

	Max silt coating size	Occurrence of silt coatings	Max carbon coating size	Occurrence of carbon coatings
Average Sami:	1.9	1.9	1.2	2.6
Average control:	1.3	2.4	1.3	1.9

The averages of the silt and carbon coating sizes and occurrences in the A, E and B horizons for both the Sámi and control profiles have been graphed in figure 4.73 and show two trends down the podzol profile. These are that silt coatings are rarely found out-with the B-horizon and that the occurrence and size of the carbon coatings will be highest in the E-horizon, due to natural illuviation and eluviation processes. The graph also illustrates that the occurrence and size of the carbon coatings is higher in the A and E horizons of the Sámi occupied sites when compared to the control samples. This fits with the established relationship between carbon coatings and disturbance; the fractionally higher maximum carbon coating size in the control B horizon compared to the Sámi B-horizon has been dismissed in this instance due to the much higher occurrence of carbon coatings in the Sámi B horizon but further analysis with a greater sample size would be needed to legitimise this.

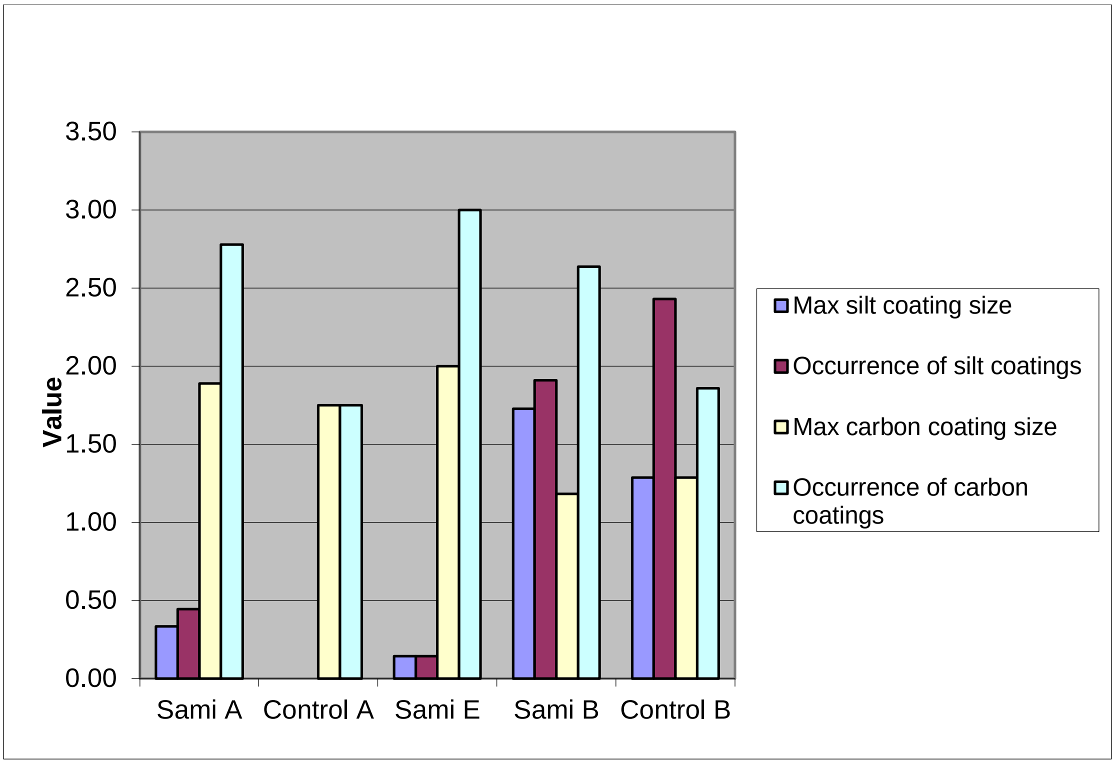


Figure 4.73: Bar graph showing the Sámi and control averages for the maximum size and occurrence of silt and carbon coatings in the A, E and B horizons of the Sámi and control sites.

4.5.3 Chemical analysis

Due to the significantly higher levels of chloride at Lass Mass Heden and Tjärdal further one way ANOVA's were carried out to compare the grouped Sámi results against the control samples and grouped European sites in order to establish whether or not a high chloride level, or indeed any other element, could be used as an indicator of Sámi occupation; the European data was included in order to meet the inputted data criteria and any comparisons will be fully explored in the discussion chapter. There was a significant difference in the titanium levels between the Sámi and control samples and, although not statistically significant, the difference in the chloride levels evident in the individual site analysis is clear through the difference between the Sámi and control samples (see figures 4.74 and 4.75 respectively). Elevated titanium levels are an established indicator of anthropogenic activity in peat soils with Hölzer and Hölzer (1998) establishing a correlation between titanium peaks in peat profiles and exposed and/or eroded soils in the vicinity. However titanium levels can be increased from burning events (Hölzer and Hölzer 1998) so due to the high frequency of forest fires in the municipality the titanium peaks seen here must remain inconclusive.

Overall three possible chemical indicators of Sámi occupation have emerged with elevated chloride and titanium levels being apparent between the Sámi sites and the control samples and with elevated phosphorous levels at Lass Mass Heden supporting the reindeer faecal material identified in the corresponding thin section slide.

```
Source    DF       SS       MS      F      P
Set        3   0.7691   0.2564   4.61  0.004
Error    136   7.5562   0.0556
Total    139   8.3253

S = 0.2357   R-Sq = 9.24%   R-Sq(adj) = 7.24%

                     Individual 95% CIs For Mean Based on
                     Pooled StDev for Titanium levels
Level       N    Mean   StDev  ---+---------+---------+---------+------
Sámi       58  0.04224 0.04949      (-----*-----)
European   42  0.05905 0.04477          (-------*------)
Control    28  0.07071 0.04898              (-------*--------)
                               ---+---------+---------+---------+------
                                0.020     0.040     0.060     0.080
```

Figure 4.74: Output from Tukey's multiple comparisons regarding the Titanium levels for the Sami, European and control samples

```
Source    DF        SS        MS      F      P
Set        3   0.02264   0.00755   5.04  0.002
Error    136   0.20358   0.00150
Total    139   0.22621

S = 0.03869   R-Sq = 10.01%   R-Sq(adj) = 8.02%


                     Individual 95% CIs For Mean Based on
                     Pooled StDev for Chloride levels
Level       N    Mean   StDev  --+---------+---------+---------+-------
Sámi       58  0.04810 0.04685                  (-----*-----)
European   42  0.02024 0.02858     (-------*------)
Control    28  0.02964 0.03825        (---------*--------)
                               --+---------+---------+---------+-------
                               0.000     0.016     0.032     0.048
```

Figure 4.75: Output from Tukey's multiple comparisons regarding the Chloride levels for the Sami, European and control samples

The overall average % elemental concentrations has been calculated using all of the data from all three Sámi sites, graphed in figure 4.76, to illustrate the movement and accumulation of key elements throughout the soil profile. As is expected for podzolic soils the percentage of most elements increases down the profile; sodium and potassium peak in the E-horizon but as the values are so low, further analysis is needed before this can be accepted as a trend of podzol soils.

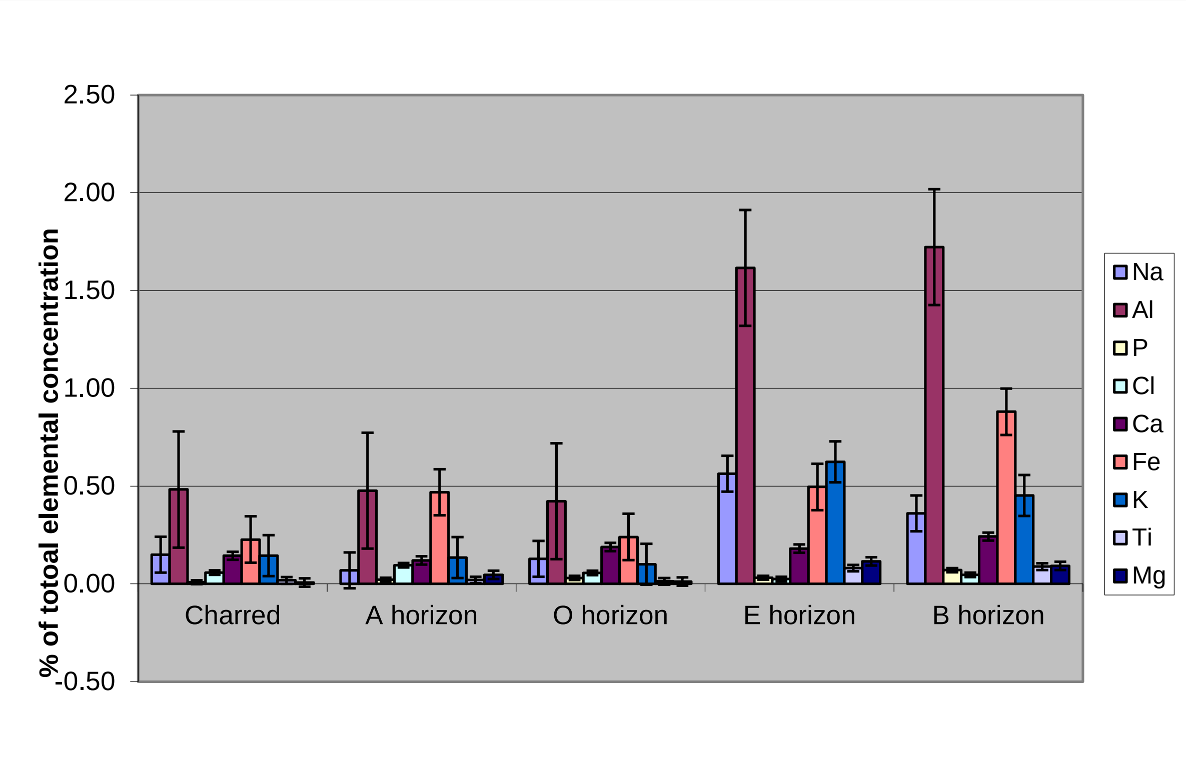


Figure 4.76: The average % elemental concentration of the O, A, E, B and charred micro-strata calculated from all Sámi sites (error bars set at 1 standard deviation)

The elemental concentrations vary between the natural A horizon and charred stratum which can be clearer seen in figure 4.77. The organic horizon has also been included in this graph due to the relationship between charring of the surface vegetation and the initiation of organic material accumulation. Although there are several smaller visual differences in the average elemental concentrations between the organic, charred and natural A-horizons the iron level in the natural A-horizon visually appears to be the most obvious and is much higher than in the charred and organic horizons. 2 sample T-tests were used to check for statistically distinct differences in elemental concentrations with chloride providing a statistically significant reading between the charred and A horizon data (see appendix 14 for data).

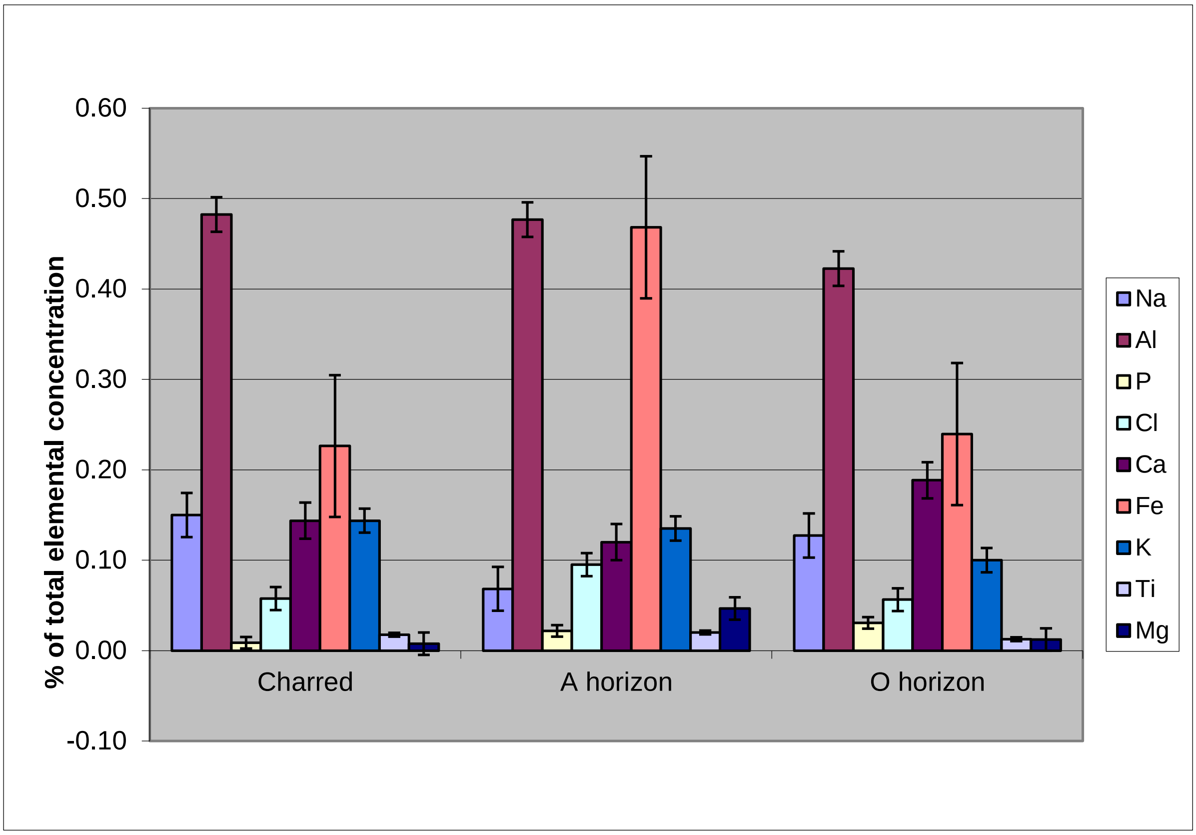


Figure 4.77: The average % elemental concentration of the O, A and charred micro-strata calculated from all Sámi sites (error bars set to 1 standard deviation)

The aluminium and iron levels recorded at each micro-stratum from the top the bottom of each profile at Lass Mass Heden has been graphed in figure 4.78 to illustrate the pattern of accumulation associated with podzolic soils further. Lass Mass Heden has been chosen for this as Prästsjödiket had histic and gleyic profiles and Tjärdal had less sample points.

The graph shoes that the distribution of iron and aluminium occasionally peaks within the A/O horizon i.e. profiles 2 and 5, very low concentrations in the E horizon before peaking in the B horizon. With the exception of profile 3 the iron and aluminium levels mirror each other in that when one decreases or increases so does the other which due to the distribution seen can be linked to eluviation and illuviation processes.

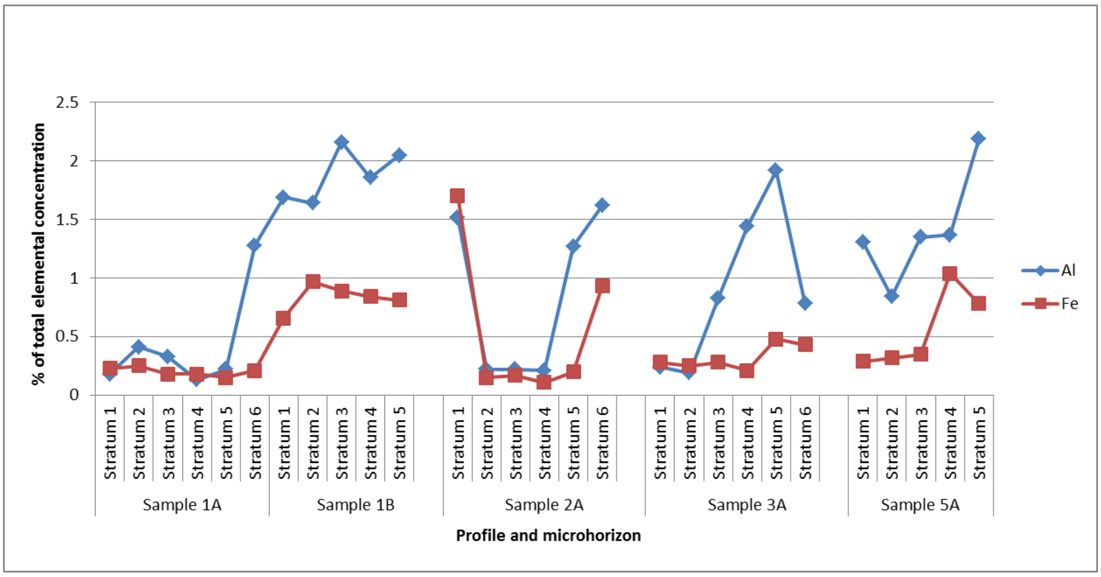


Figure 4.78: The aluminium and iron levels for each micro-strata (from top to bottom of profile) at Lass Mass Heden

4.5.4 Magnetic susceptibility

The magnetic susceptibility of all bulk soil samples were taken in order to establish areas of burning so that it could be tied to the micromorphology results. The data for all sites has been graphed together in figure 4.79 where a clear increase in magnetic levels can be seen at Lass Mass Heden and Tjärdal in comparison to Prästsjödiket; the peaks seen fit with charcoal horizons in the related thin section slides. The elevated levels seen in Lass Mass Heden and Tjärdal have been attributed to the difference in geology and soil type rather than burning activity; they have an acid to intermediate intrusive bedrock with podzol soils compared to the sedimentary bedrock with a mix of peat, gley and podzol soils at Prästsjödiket. The links between the peaks in the podzol soils and the inclusion of charcoal within the corresponding thin section slides does however indicate that in areas not subject to frequent forest fires magnetic susceptibility peaks in podzolic soils are a reliable indicator of past burning activity.

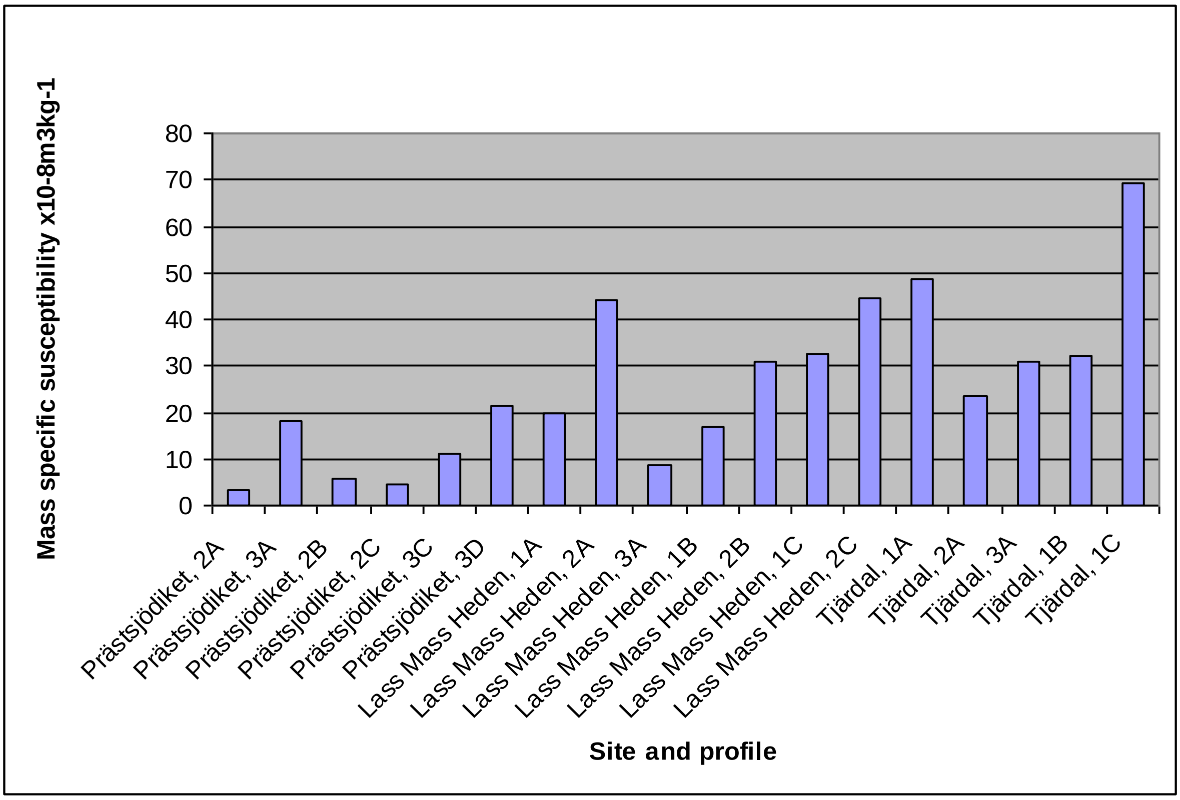


Figure 4.79: Mass Specific Magnetic Susceptibility values for Sami sites

The mass specific magnetic susceptibility was then looked at per horizon type but showed a great level of variation between profiles, most likely due to varying levels of activity and the afore mentioned bedrock and soil differences. Therefore the average for the A, E and B horizons across the three sites was calculated and graphed so that any trends could be easily seen (see figure 4.80). The highest level is present within the B horizon, followed by the A horizon and finally the E horizon, something which was not apparent from the individual site analysis. This fits very well with the podsolization processes, whereby there will be a higher level in the A horizon where the activity has taken place and immediately following the burning event, but as materials move down profile through the E-horizon, which is typically reduced of most materials, these materials are then deposited in the B-horizon giving the pattern seen here.

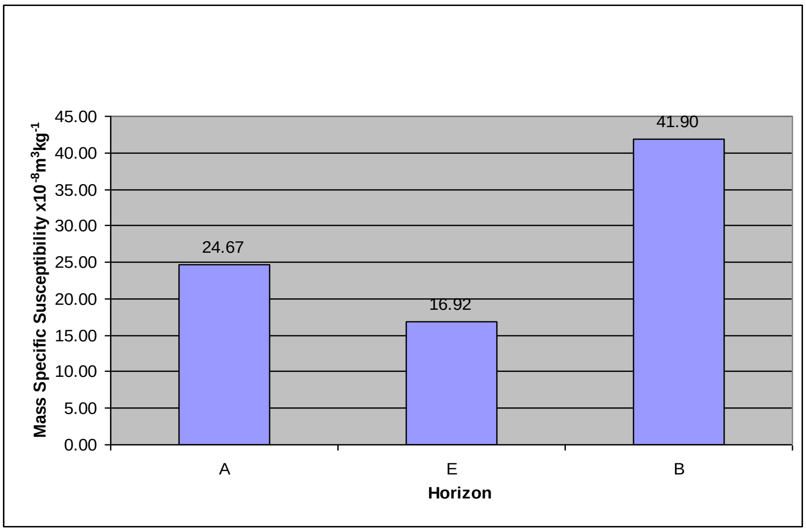


Figure 4.80: The average magnetic susceptibility values for the A, E and B horizons as calculated from all three Sámi sites

4.6 The Sámi soilscape

The key findings from all of the analysis for each site will be briefly summarised per analysis type so that a final, updated table showing what cultural indicators are associated with Sámi activity can be created.

The two main indicators to emerge from the micromorphological analysis of the Sámi samples are the disturbance pedofeatures and inclusion of reindeer faecal material; the charred strata and the resulting organic accumulations at the study sites have all been deemed natural but if occurring alongside disturbance pedofeatures could be used as an indicator.

The reindeer faecal matter occurs in only a few of the samples taken, which due to its organic composure is expected; as the material will be readily re-worked in biologically active soils. The occurrence of reindeer faecal material has been established due to control samples of reindeer excremental material collected from Tjärdal being manufactured into a thin section slide and studied. The control sample provides a strong basis for comparison which once any subtle changes from age, biological activity, level of decomposition and vegetation consumed are taken into account will provide a reliable indicator for future work.

The charring of the surface vegetation followed by an accumulation of organic materials has been attributed to the frequent, naturally occurring forest fires in the area (Zackrisson 1977; Grandström *et al* 1996; Grandström 2001). All of the charred micro-strata in the podzol profiles directly overlie the E-horizon and are typically low to medium intensity burnings of surface vegetation, and could indicate that the original A-horizon was extremely shallow, as there is often no trace of it after the burning. The organic accumulations show increased levels of biological activity directly above the charred micro-strata, however at some point the biological activity stagnates and ceases unless the area is exposed to secondary burning episodes which renews the accumulation of organic material and associated biological activity. As the change in vegetation cover post burning is known to form favourable grazing areas, the high frequency of the fires in this area may have indirectly influenced the settlement of the Sámi at these sites for those who herded Reindeer; if the herders are following the reindeer and the reindeer incorporate the best grazing areas into their migration route, it is plausible that they will favour areas with a high forest fire frequency if they offer better grazing.. There are two examples of tree throw in the micromorphology slides (profile 4 at Tjärdal and profile 3 at Lass Mass Heden) with the one at Tjärdal having occurred long enough before the burning event for the tree roots to have decomposed and the on at Lass Mass Heden having occurred immediately prior to, or during, a burning event. Due to the lack of any additional disturbance features, both were deemed as natural but if there is evidence of tree throw immediately before or during a burning event with their being evidence of disturbance, amendment or a lack of vegetation cover after the burning episode it could designate the fire as anthropogenic in origin as part of a slash and burn style of clearance.

There was also a nice example of the removal of a small number of trees and turf at Prästsjödiket which has been linked to the collection of wood and turf, most likely for the construction of cots. This was not seen in any of the other sites and demonstrates that evidence of tree and turf removal will not always be found, even if it is known to have occurred by the visible presence of hearth stones; tree throw followed by a medium intensity burning episode for clearance with an overlying organic accumulation rich in spruce needles indicating that the tree removal was limited with very thin organic strata directly overlying E-horizon material near-by.

The disturbance pedofeatures are not so obvious and can be related to both the burning episodes and disturbance. The presence and size of organic carbon coatings are highest in charred strata, or the underlying E-horizon, due to the increased availability of carbon, but elevations in size and number of the coatings in physically disturbed profiles are also evident at Lass Mass Heden in profile 3. As a result, if a) the coatings occur out-with the charred or E-horizon, b) they occur alongside other evidence of disturbance or c) if in the charred or E-horizon they are larger than size 2 and occur on more than 5% of the mineral grains (>5%), then they can be taken as an indicators of disturbance.

The identification of chemical components within the soil samples using the Scanning Electron Microscope has confirmed the natural illuviation and eluviation podzolisation processes anticipated in podzolic soils, and the possibility that elevations in chloride and/or titanium from the natural levels could be indicators of Sámi occupation. Peaks in the phosphorous level, a traditional indicator of anthropogenic activity and/or occupation, was also noted at the Lass Mass Heden site and has been tied to reindeer husbandry on site.

The magnetic susceptibility of the soils fitted with the burning episodes identified through the micromorphological analysis, and as such has been deemed a reliable indicator of burning activity. Yet, due to the high frequency of naturally occurring forest fires in the region (Zackrisson 1977; Grandström *et al* 1996; Grandström 2001), it cannot be used as an indicator of Sámi occupation unless paired with other supporting indicators; even in areas where natural forest fires do not occur or are rare, magnetic susceptibility should be used to complement other analysis rather than be used as a lone indicator. Magnetic susceptibility in the field in areas where forest fires are rare could prove to be extremely valuable in identifying anthropogenic activity; if the magnetic susceptibility probe is teamed alongside a corer then it will allow for past charred landscapes to be identified through a simple core rather than several soil transects being dug.

Table 4.11 contains two rows of data, firstly the 'anticipated' indicators expected in acidic podzol soils at known Sámi sites as identified in chapter 2 and the second row, which contains information which has been updated from the analysis of bulk soil and thin section samples collected at known Sámi sites in Northern Sweden. None of the cultural indicators anticipated as occurring at the Sámi sites have been confirmed however, other indicators have been identified. The table has simple yes or no data rather than levels of disturbance and/or quantative values. Consequently it must be used alongside in-depth analysis when trying to establish the source of disturbance at a site of unknown occupation; the results from the study sites in this thesis can be used as comparative data.

Table 4.11: Table detailing cultural indicators associated with Sámi occupation estimated in chapter 1 and those confirmed by analysis of bulk soil and thin sections collected at known Sámi sites in northern Sweden

Visual			Micromorphological										Chemical		Added	
	Ploughmarks	Disturbed horizons	Bone*	Charcoal	Burnt material	Ash	Type 113 fungal spores	Mite excrement	Coprolites	Phytoliths	Coatings & infillings	Microstructure	Elevated P	Magnetic susceptibility	Elevated Cl level	Elevated Ti
Anticipated	×	?	×	✔	?	×	?	?	×	×	?	✔	?	✔	N/A	N/A
Confirmed	×	✔	×	×	×	×	×	×	✔	×	✔	×	✔	×	?	?

**Either marine or terrestrial bone*

Key:

✔	Yes
×	No
?	Unknown

Chapter 5: The European Landscape

5.1 Introduction

The European landscape is predominantly one of overlap. The European settlers occupied the Sámi summer coastal areas before moving their settlement boundary inland, into the Sámi winter settlement and grazing areas; a full history of this movement and the known and anticipated cultural activities at these sites have been explored in chapters 1 and 2.

5.2 Kåddis

5.2.1 Background

Kåddis is situated on sedimentary bedrock and podzol soils (Swedish Geological Society, 2010) and is understood to have been settled during the Middle Ages with the first historical record relating to it dating to AD1324, when a childless couple left their home to the Uppsala cathedral (Västerbotten museum, 1991); see figure 5.1 for location map. The name Kåddis is derived from the Sámi word for beach, which may indicate a Sámi presence post European settlement (Västerbotten museum, 1991). Kåddis was home to a Hanseatic merchant during the 14th century which may be due to its proximity to the harbour village of Baggböle which is 2km away (Västerbotten museum, 1991).

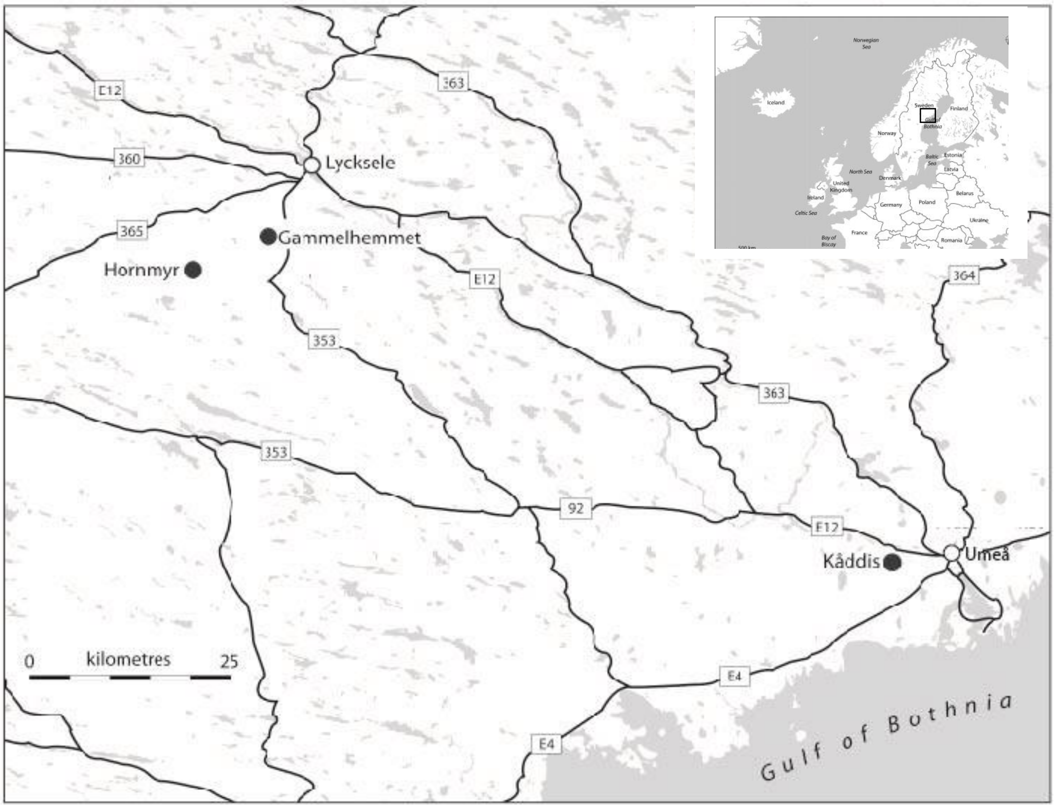


Figure 5.1: Map showing location of all sites with European sites distinguished by black circular marker; created using Illustrator from a Google map base

5.2.2 Study locations

Kåddis has been populated since the middle ages and was located next to an important trade harbour during the 14th century (Västerbotten museum, 1991); as the land has risen through isostatic recovery, the harbour has kept moving downstream until its present location in Umeå. Kåddis is still inhabited today with several homes and farms with the majority of land being used for crop growing; a site map showing the profile locations is shown in figure 5.2 with an accompanying satellite image being shown in figure 5.3.

Profiles 1, 2 and 3 are all located in grass fields neighbouring, but not directly adjacent to, current farm buildings. Profile one has a deep anthric topsoil, which fits with the plaggen criteria outlined by the FAO and overlies bands of clay and course sands, most likely deposited during past flood periods, and becomes more compact with increasing depth, which is most likely a result of freeze thaw processes. There is an area between the topsoil and the underlying horizon where the material is mixed and could indicate that the soil has been ploughed.

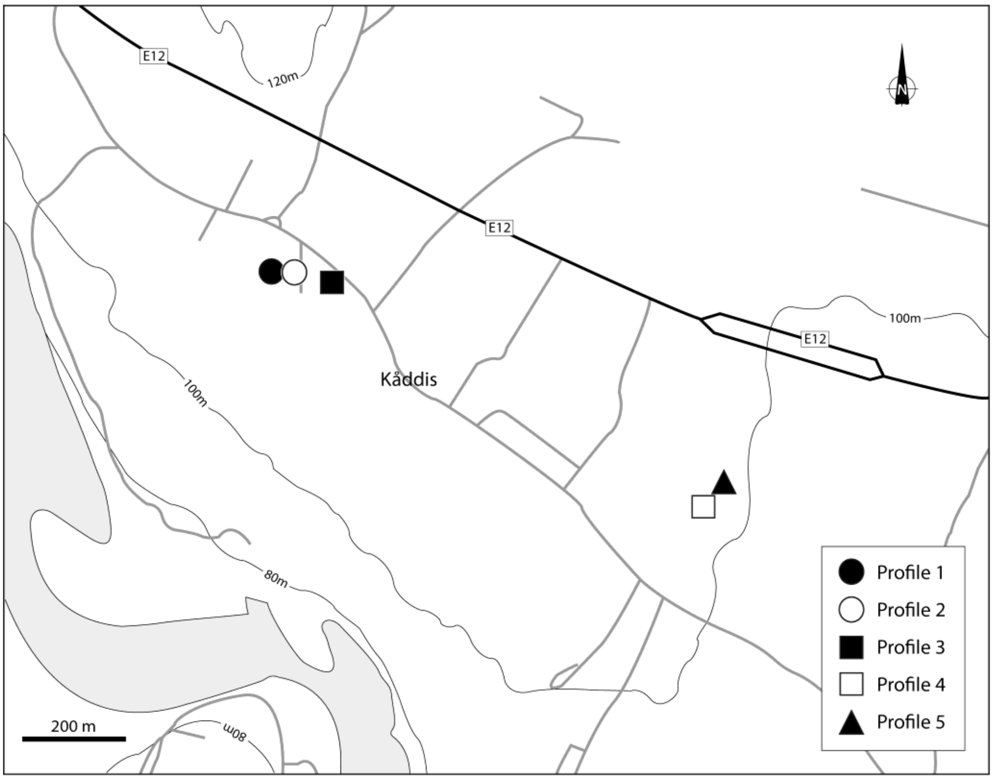


Figure 5.2: Map showing location of all profiles within the Kåddis site

Figure 5.3: Screen grab of the Google satellite image showing profile locations (Google Maps, 2013)

Profile 2 is similar to profile 1 with the exception of the material underlying the topsoil. In profile 1 there were grey coloured clay bands but in profile 2 these have been replaced by bands of dark red sand. The underlying horizons are also noticeably more mixed with patches of albic horizon material visible at the bottom of the anthric topsoil; figures 5.4 and 5.5 show photographs of the profile with annotations showing evidence of biological mixing.

Figure 5.4: Photograph of profile 2 at Kåddis

Figure 5.5: Annotated photograph of profile 2 at Kåddis

Profile 3 is similar to profile two in that it has an anthric topsoil overlying bands of sand, however, the darker bands are not as well pronounced and do not appear as often. There is also a diagonally shaped iron stain underlying the topsoil which will have been formed from illuviation processes.

Profile 4 is located in pine woods between the previous sites and Prästsjödiket, but nearer the Kåddis sites, and consists of a podzol soil with well-developed albic and spodic horizons. There is a large irregularity in the albic horizon in the middle of the profile most likely caused by a tree root, which has decomposed and been filled in by the overlying albic horizon material. Above the albic horizon at the top of this irregularity is a pocket of charcoal, which could either be an infill material, the cause of the tree roots death or a possible second surface. The sand at the bottom of the profile, like the previous profiles, is very compact.

Profile 5 is located further along the transect and although they are both in the same wood the vegetation at profile 5 has more shrubbery than profile 4. The profile is again a podzol but has a much deeper histic topsoil and albic horizon than profile four with small round pockets of yellowish material which are the result of root disturbance.

5.2.3 Chronology

There was no visible charcoal at any of the profiles at Kåddis during the fieldwork, so charcoal samples had to be obtained from the few fragments present in the bulk soil samples; see table 5.1 for full sample information and figure 5.6 for radiocarbon plot, sample location is marked on the digitised soil profile (see figure 5.9). A charcoal sample, identified as *Pinus sylvestris*, taken from the anthropogenic horizon at profile 1 has been dated to AD1435-1618 (see table 5.1 and figure 5.6), which, even though the exact occupation date of the site is unknown, encompasses a large period of occupation and indicates that the charcoal is anthropogenic in origin, most likely having been added/applied to the topsoil as part of a plaggen style of enrichment and cultivation; due to the depth of the anthropogenic topsoil and the references to this site in the Middle Ages, it has been presumed that the land has been cultivated throughout and would have acted as a barrier for any neighbouring forest fires as the short nature of vegetation/crops associated with cultural soils could not have supported the spread of a forest fire.

Table 5.1: Table containing information on location, type and age of all radiocarbon dated material from Kåddis

Site reference	Sample reference	Depth of sample (cm)	Lab code	Material	Radiocarbon Age BP	Calibrated Date (≥95.4%)
Kåddis	Sample 1A	11	26894 (GU20386)	Pinus sylvestris	410±25	AD 1435-1618

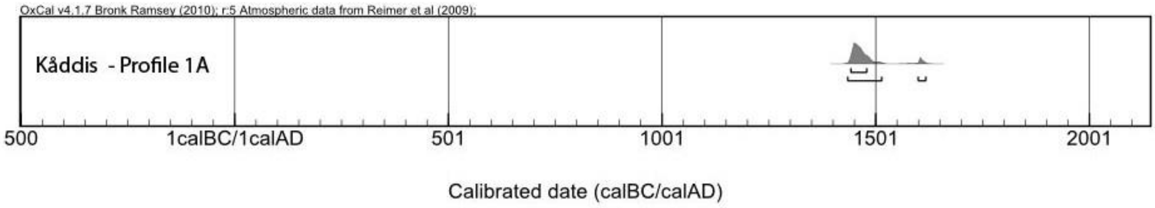


Figure 5.6: Radiocarbon plot showing the calibrated dates for the sample dated from Kåddis

5.2.4 Micromorphology

5.2.4.1 Profile 1

5.2.4.1.1 Description

Slide 1B was taken at a depth of 40cm; see figure 5.9 for soil profile drawing and location of slide and table 5.2 for the micromorphology description tables. The mineral grains throughout are rounded to sub-rounded, well sorted and well accommodated and include a trace of composite grains but overall the grain size decreases as depth decreases.

Slide 1A was taken from the anthropogenic topsoil overlying the flood deposits at a depth of 15cm and incorporates two anthropogenically enhanced strata; the upper stratum is significantly more enhanced than the lower. The lower stratum has the same well sorted and sub-rounded mineral grains seen in the lower strata of slide 1B but in a more open structure (30% void space and un-accommodated vs. 5-20% pore space and well accommodated coarse material in slide 1B) as well as patches of phytolith rich turf based amorphous organic material (5% of stratum, phytoliths common) and E-horizon material. Very few of the mineral grains have a size 1 organic carbon coating.

The upper stratum is visibly identifiable from the lower by a marked colour change caused by its high organic content (34% compared to 5% in lower stratum). The organic material is predominantly fine and part of the organic rich close porphyric b-fabric; course material is well accommodated within the dense organo-mineral b-fabric. Decomposed turf material containing few fractured phytoliths and diatoms are visible within the highly homogenised organo-mineral microstructure as well as a trace of charcoal not seen in the lower micro-stratum but due to the highly decomposed and mixed nature of the fine organic material possible traces of manure cannot be reliably identified.

5.2.4.1.2 Interpretation

The sub-rounded, well sorted and accommodated nature of the mineral material in the lower profile which decreases in size as depth decrease indicates that the material is fluvial in origin and has been deposited during flood periods but that these flood periods have decreased in intensity over time; the decreasing intensity could also be linked to the isostatic uplift of the area. The micro-laminations of organic material signify standstill periods which and occur between the mineral deposits indicating a cyclical, possibly seasonal, pattern of a flood episode followed by stability and subsequent organic accumulation.

The flood deposits are overlain by the anthropogenically enhanced topsoil, which can be further split into two strata. The lower stratum is not as well enhanced as the upper and is derived from the same well sorted sub-rounded mineral material seen in the lower stratum. The structure is however more open, more organic rich and contains deposits of phytolith rich turf material; the phytolith/diatom material is indicative of a wet environment (Fox and Tomorai, 1990), and fits with the emerging flood landscape identified from the lower slide (see figures 5.7 and 5.8 for photographs). The change in structure and the inclusion of highly decomposed turf material indicates that the stratum has had turf material added and been mixed in preparation for cultivation; due to the similar nature of the mineral material throughout the lower stratum it is unclear whether any mineral material was added to this profile. Very few of the mineral grains have a size 1 organic carbon coating indicating that there has been movement of fine organic material down profile.

The upper stratum is identifiable by a marked colour change which is caused by the sharp increase in organic matter content from 5% in the lower to 34% in the upper. The organic material forms a highly homogenised, and therefore heavily worked, soil which shows evidence of the input of turf material; the turf material is well decomposed and contains fractured phytoliths and diatoms. The homogenised structure and inclusion of fractured phytoliths and diatoms further indicates the highly worked nature of the soil; highly worked refers to a high level of mixing and intense use. A trace of fragmented micro charcoal is present within this stratum which was not visible in the lower. It is highly likely that due to the free draining nature of the underlying sand deposits that a large quantity of any micro charcoal, whether naturally present from forest fires or added as part of the soil management regime, has percolated down profile beyond what was sampled.

Overall, profile 1 has been podzolic with a collection of cyclical flood deposit material and thin organic accumulations during standstill periods, which has been prepared for cultivation by the addition of turf material and mixing. After this initial preparation an increased level of turf material as well as charcoal has been applied to the soil before being intensively worked resulting in the highly homogenised, porphyric microstructure.

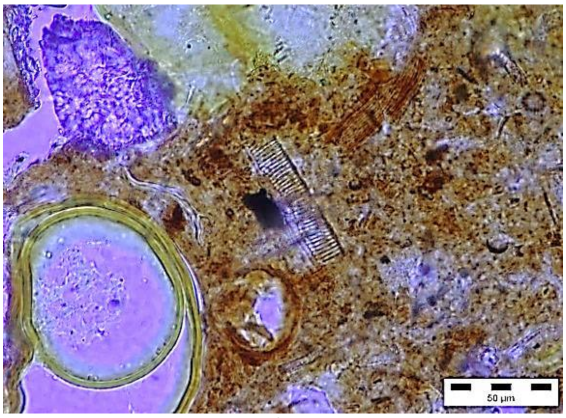


Figure 5.7: Diatom within turf material PPL x 40 mag

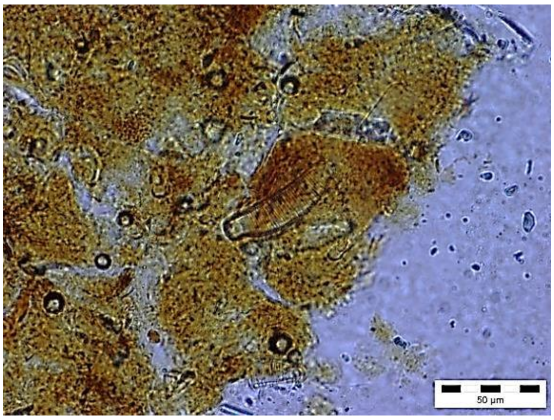


Figure 5.8: Diatoms & phytoliths in turf material PPL x 40 mag

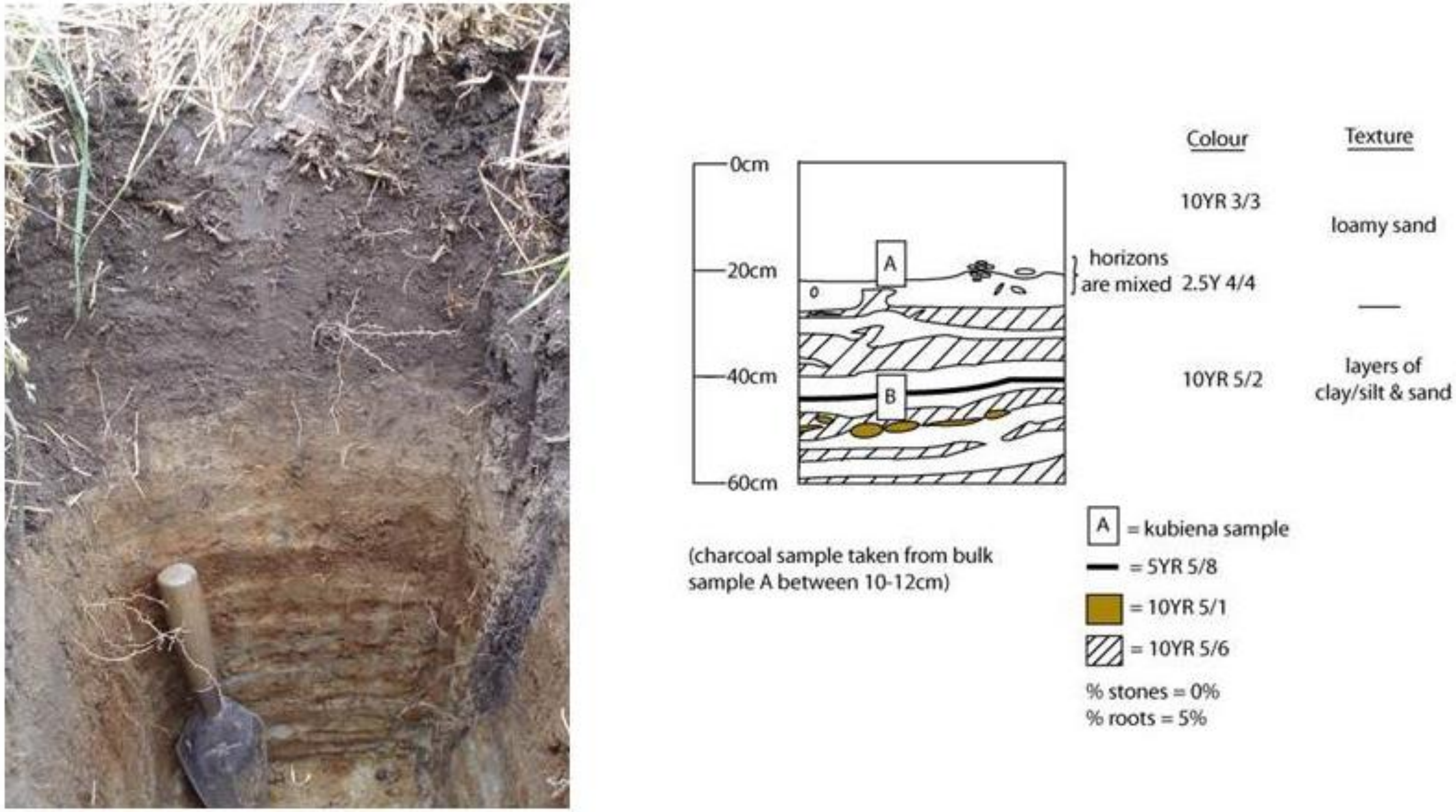


Figure 5.9: Photograph and soil profile diagram of profile 1

5.2.4.2 Profile 2

5.2.4.2.1 Description

Slide 2B was taken at a depth of 40cm; see figure 5.12 for soil profile drawing and location of slide and table 5.2 for the micromorphology description tables. The slide has an open single grain microstructure with well sorted and un-accommodated mineral grains and a coarse to fine ratio of 10/1 with a trace of organic material. Organic carbon coatings (size 1) are common.

Slide 2A was taken at a depth of 18cm and incorporates a coarse grained fluvial deposit, a finer grained fluvial deposit from a less intensive flooding episode, small pockets of the original podzol soil and the overlying anthropogenically enhanced topsoil. The lower stratum is similar to the coarse grained fluvially deposited mineral material seen in slide 2B but is not as coarse and has a higher organic content; 35% organic material vs. a trace in the lower slide and mineral grains up to size 2 with a coarse to fine ratio of 4/1 compared to size 3 grains with a coarse to fine ratio of 10/1. The organic material occurs in an undulating lamination near the top of this micro-stratum. Very rare organic carbon coatings are present on the mineral grains (size 1).

The overlying fine mineral stratum is highly compact and derived from poorly sorted coarse material intermixed with pockets of fine mineral material and decomposed turf material. The upper anthropogenically enhanced topsoil has partially sorted coarse material, turf fragments and very few size 1 organic carbon coatings on the mineral grains.

5.2.4.2.2 Interpretation

The single grain microstructure of well sorted, un-accommodated material in slide 2B indicates that the mineral material was deposited by the same flood event and that any fine mineral or organic material (only a trace of organic material throughout) has migrated down profile. The common size 1 organic coatings can also be linked to the movement of fine organic material from higher up in the profile.

Slide 2A however incorporates several strata, starting with flood deposits from less intensive flood episodes than seen in the lower slide, evidenced through the finer size of mineral grains, the remaining small pockets of the original podzol, evident through the remaining pockets of bleached E-horizon material, and the overlying anthropogenically enhanced topsoil. The flood deposits are separated by organic accumulations that indicate standstill periods; indicates standstill as a stable environment is required for organic material to accumulate. The reduction in deposit size and intensity coupled with the standstill periods allowing for organic accumulations indicates a changing environment which is becoming more stable and subject to fewer, less intense flooding events over time. The inclusion of organic coatings throughout is indicative of the movement of fine organic material down profile which will be related both to the eluviation processes of the podzol element of the soil but also the percolation of water through the underlying freely draining sand deposits.

The overlying fine mineral stratum shows signs of disturbance and mixing through the poorly sorted nature of the coarse material; pockets of fine mineral material lie next to decomposed turf material and mixed pockets of course and fine mineral material (7% organic material). This indicates that the soil has been mixed/turned over as part of the initial clearance and settlement of the site. The difference between the natural soil and the anthropogenically modified, more compact stratum is visible though a distinct change in the mineral grain size and compaction level within the soil (see figures 5.10 and 5.11 for photographs).

The poorly sorted nature of the lower anthropogenic stratum indicates that either there has been several micro-strata of differing sized mineral material which has been mixed together in order to form the stratum, or that mineral material has been added from elsewhere in the site. Turf has been added to the profile, but in a reduced quantity to that seen in profile 1, and the amorphous organic material present has a trace of fractured phytoliths indicating that the profile has been less intensively manured. The organic carbon coatings can be related to the trace of micro-charcoal within this micro-stratum and is the origin of the thin organic carbon coatings in the lower micro-stratum; fine organic material has leached down profile.

Overall, this profile has been formed from fluvially deposited mineral material, which has been prepared for cultivation by the mixing of either the overlying group or single mineral stratum with an input of turf material. The soil has been reworked to the point that only traces of the original E-horizon material are visible in the lower topsoil. The on-going input of 'added' materials and cultural activity at this profile has been much less intensive than that of profile 1 and has resulted in a poorly mixed, organic poor topsoil.

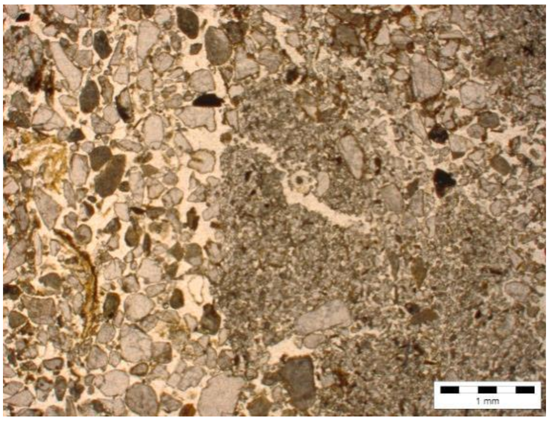


Figure 5.10: Change in mineral grain size between micro-strata PPL x2 mag

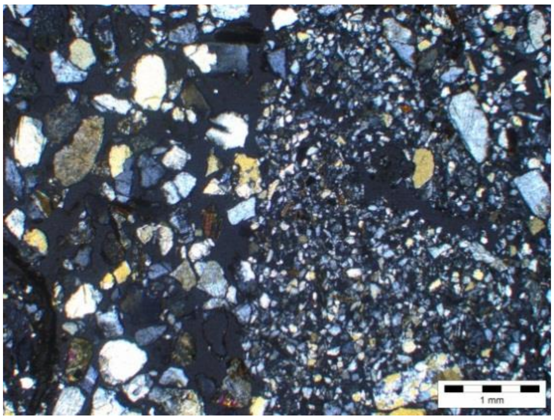


Figure 5.11: Change in mineral grain size between micro-strata XPL x2 mag

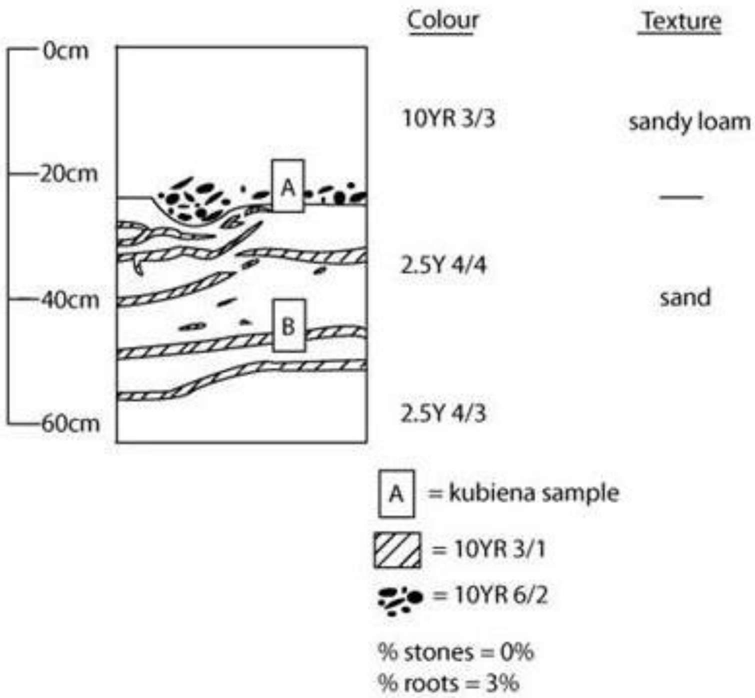


Figure 5.12: Photograph and soil profile diagram of profile 2

5.2.4.3 Profile 3

5.2.4.3.1 Description

Slide 3B was taken at a depth of 18cm; see figure 5.13 for soil profile drawing and location of slide and table 5.2 for the micromorphology description tables. The lower stratum is partially sorted with rounded mineral grains ranging from size 1 to 3 and contains randomly occurring amorphous organic material. The overlying micro-stratum is much more mixed than the lower. The mineral material is large for a natural upper stratum (size 3) and partially sorted with organic carbon coatings are common (size 2).

The ploughmark/scar is highly organic and is found to the top left of the lower micro-stratum; 10% quartz with common size size 3 organic carbon coatings (see figures 5.11 and 5.12 for photographs). It is formed from a mix of wood based charcoal, lignified tissue and fine amorphous organic material, and has been lightly mixed with the surrounding mineral material; the turf material contains no phytoliths or diatoms.

5.2.4.3.2 Interpretation

The lower stratum consist of partially sorted, rounded mineral grains which indicates that the material is fluvial in origin, but from different flooding episodes. The inclusion of amorphous organic material randomly throughout the stratum indicates that it has either migrated down profile, rather than formed during a standstill period, or that it has been mixed in when the mineral material was mixed. The presence of common size 2 organic carbon coatings can be linked to the charcoal content of the upper stratum, and adjacent organic rich ploughmark.

The overlying stratum is much more mixed with the organic material having been incorporated into an organic rich, homogenised b-fabric rather than occurring as decomposing turf fragments as seen in the lower stratum. The mineral material is large and partially sorted which does not fit with the typical decrease in mineral grain size with proximity to the surface. This indicates that the mineral material has been added to the profile; as there is evidence of amendment in the stratum underlying this it cannot be the result of mixing several in situ strata; the common size 2 organic coatings can be linked to the charcoal content of the micro-stratum.

The turf material has no phytoliths or diatoms indicating that it has originated from a woody environment different to the wet environment where the turf material in profiles 1 and 2 originated from. This material has been added as part of the initial preparation for cultivation and has been poorly mixed, resulting in the random spread of turf material throughout the lower micro-strata. The wood based nature of the organic ploughmark indicates that the site has been cleared and partially charred (traces of charcoal) with the woody vegetation being incorporated into the soil, alongside the surface vegetation, rather than outsourcing turf from the same wetter environments used for profiles 1 and 2; see figures 5.14 and 5.15 for photographs of the organic rich ploughmark. The profile has been prepared for cultivation by the clearing and addition of the overlying woody vegetation before being mixed with the fluvially deposited mineral material; contemporary cultivation will have affected the microstructure, but not mineral content, of the upper micro-stratum.

Overall this profile has been a wooded fluvial deposit which has been cleared for cultivation, with the cleared vegetation being added to the soil during the initial mixing; mixing was poor. The soil has been cultivated with the further addition of turf material over an extended period of time which has resulting in a deep, mixed topsoil with a marked change in the organic microstructure.

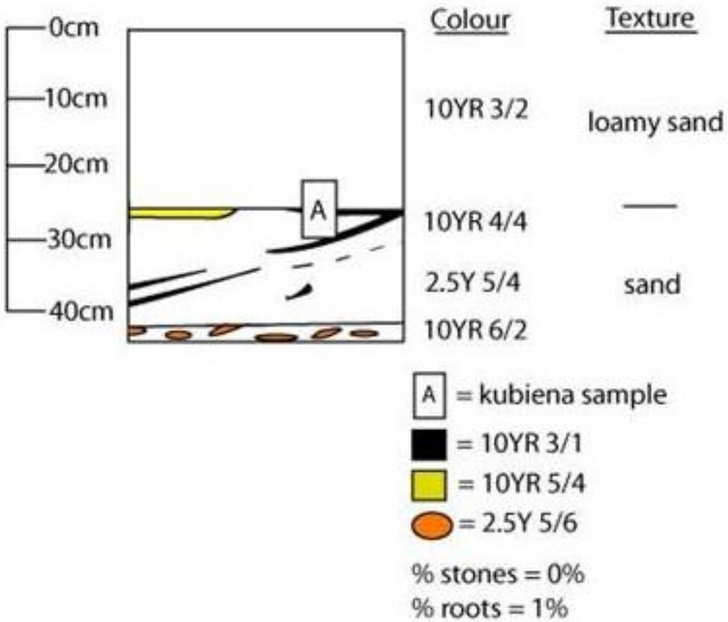


Figure 5.13: Photograph and soil profile diagram of profile 3

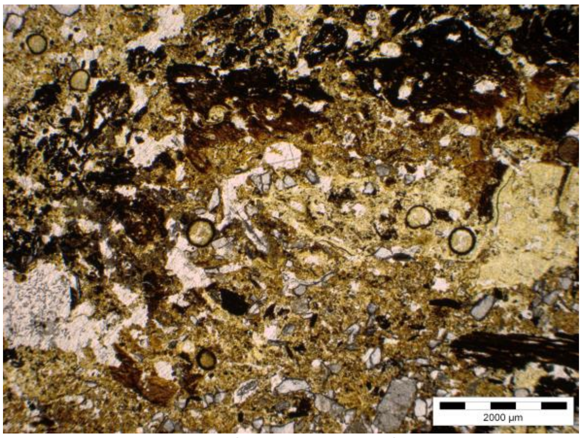


Figure 5.14: Photograph from the centre of the organic rich ploughmark PPL x1.25 mag

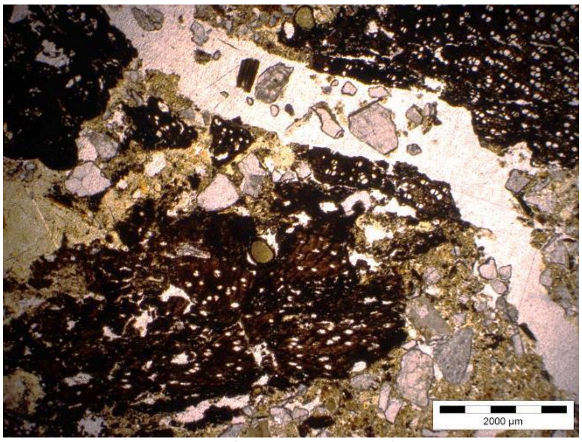


Figure 5.15: Photograph from the centre of the organic rich ploughmark PPL x1.25 mag

5.2.4.4 Profile 4

5.2.4.4.1 Description

Slide 4B was taken at a depth of 5cm; see figure 5.16 for soil profile drawing and location of slide and table 5.2 for the micromorphology description tables. The lower stratum has a single grain microstructure with iron staining on 20% of the mineral material and 12% organic content which then reverts to a highly organic, weak crumb microstructure with 5% iron staining in the upper stratum of the slide. There are very few, size 1 organic carbon coatings throughout with the overlying organic accumulation (only 5% mineral content) having been very biologically active.

Slide 4A was taken at a depth of 0cm and incorporates an E-horizon with a charcoal inclusion (micro-stratum 3) and separate organic deposit (micro-strata 4) and an overlying organic accumulation. The E-horizon mineral grains are sub-rounded and well sorted and are beginning to form small bands of fine mineral material within its single grain microstructure. There is a trace of charcoal and 10% organic content.

The burning episode has occurred after the main area of the root channel has in-filled with the surrounding E-horizon material but has left a slight basin/sink which has then been in-filled with the charcoal and organic deposits which are angled down into the bottom right corner of the slide fitting with the contours of the root channel; the organic deposits here are a continuation of the organic deposit seen in slide 4B. The charred strata is not uniform in size and does not span the width of the slide. The charcoal is partially decomposed and very few of the mineral grains have organic carbon coatings.

The upper organic accumulation occurs directly above the E-horizon (micro-strata 2) and its trace of micro-charcoal and subsequent size 2 organic carbon coatings on mineral grains (rare). This accumulation is again almost wholly organic (trace of quartz). Both patches have rare size 2 organic carbon coatings. This, and the next, profile are located half way between this site and Prästsjödiket (Sámi) and is being used as the control sample for both sites and shows no evidence of anthropogenic activity be it Sámi or European in origin.

5.2.4.4.2 Interpretation

Slide 4B contains two strata which both indicate that they are fluvial in origin; the deposits are sub-rounded with a single grained and weak crumb structure. The well sorted nature of the material indicates that it was deposited from a single event with the organic content (12% of stratum) resulting from post-depositional root growth.

The high percentage of iron staining (20% of mineral material) indicates the initial formation of a B-horizon as the iron content has eluviated down profile and been deposited here, resulting in an accumulation of iron typical of a podzol B-horizon. The inclusion of organic carbon coatings are also linked to the eluviation processes but also to the elevated availability of carbon from the charcoal content of the overlying micro-strata. The overlying organic deposit is undisturbed which indicates that the disturbance seen in the profile is from the natural decomposition and refilling of a tree root channel rather than from anthropogenic impact; the shape of the deposit is fitting of a tree root where the root has decomposed leaving a void which has back filled with material from the upper strata.

The E-horizon has formed from alluvially deposited material (mineral grains sub-rounded and well sorted) and is beginning to form small bands of fine mineral material within its single grain microstructure. The trace of charcoal and 10% organic content within this stratum has originated from root growth and/or percolated down from the charcoal and organic deposits.

When viewing the soil profile the charcoal stratum occurs before the organic accumulation as anticipated, but the charcoal band is not constant within the micromorphology slide. The charcoal micro-stratum appears as a discontinuous layer underlying the organic accumulation to the right of the slide which leads into a circular accumulation to the left of the slide. The charcoal is partially decomposed, as seen in other podzolic soils, and has begun to migrate down profile. Very few of the mineral grains have organic carbon coatings; which can be linked to the charcoal content and increased availability of carbon.

The upper organic accumulation is almost wholly organic which indicates that there has been no disturbance to the profile. The burning episode and subsequent organic accumulation fits with the emerging pattern of organic accumulations following natural burning episodes from forest fires. Similarly the presence of organic carbon coatings is linked to the increased carbon availability from the burning episode.

Overall this profile fits with being in a wooded area due to the tree root decomposition and subsequent infilling and the high level of biological activity seen in the organic accumulations is typically associated with pine forests. Asides from the natural death, decomposition and refilling of a tree root path the site has been undisturbed until a light charring episode, was natural in origin, which resulted in the anticipated accumulation of organic material.

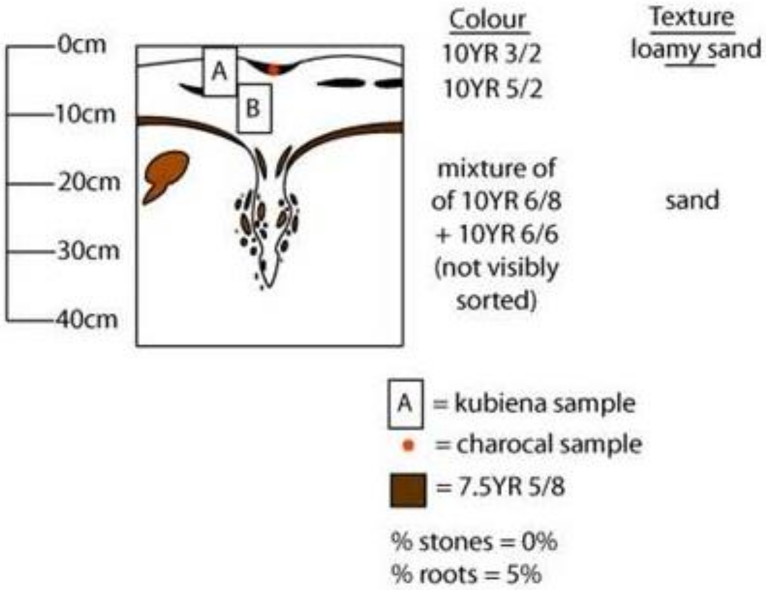


Figure 5.16: Photograph and soil profile diagram of profile 4

5.2.4.5 Profile 5

5.2.4.5.1 Description

Slide 5A was taken at a depth of 1cm; see figure 5.19 for soil profile drawing and location of slide and table 5.2 for the micromorphology description tables. The E-horizon consists of sub rounded, well sorted and iron depleted mineral grains, separate patches of fine mineral material and/or amorphous organic material and large root material.

The boundaries between the E-horizon and overlying past land overlap with the organic rich (2% quartz) b-fabric of the overlying micro-stratum having partially migrated into the upper level of the developing E-horizon; see figures 5.13 and 5.14 for photographs. This material contains a trace of partially dissolved charcoal material which has been reworked by biological activity (30% spheroidal excremental material). Size 1 organic carbon coatings are present on very few of the mineral grains. The boundary between this strata and the overlying organic accumulation are again unclear and are indicated by the colour change from greyish orange to orange, by the reduction in mineral material from 2% to a trace and the change in organic material from a highly reworked excremental rich fine organic stratum to a an organ and tissue residue rich coarse organic micro-stratum.

The overlying charred stratum is almost wholly organic and contains 40% charcoal. The central area within the upper stratum has been highly reworked.

5.2.4.5.2 Interpretation

The E-horizon is formed from fluvial deposits and is poorly developed as although the mineral material is iron depleted the microstructure is granular; the sub-rounded, well sorted nature of the mineral grains is indicative of fluvial transported material. However even with established podzolisation processes (iron depletion, movement of organic material down profile and accumulation of fine mineral material) the stratum is not too acidic as to inhibit root growth; root material contains parenchymatic tissue indicating that it's fresh rather than preserved historic material. Rare organic carbon coatings on the mineral grains (size 1) can be linked to the migration of fine organic material from the overlying partially charred past land surface.

The E-horizon and past land surface boundaries are blurred due to the on-going eluviation processes trans-locating the material down profile. This material contains a trace of partially dissolved charcoal material and has been heavily reworked by biological activity (30% spheroidal excremental material) and can be linked to the size 1 organic carbon coatings on very few of the mineral grains. The boundary between this strata and the overlying organic accumulation are again unclear and are indicated by a change in the colour and mineral composition of the soil as well as a reduction in biological activity within the organic component of the soil. There are no signs of disturbance or anthropogenic activity within the horizon.

The micro-charcoal present within the central, highly reworked stratum could have been deposited from burning episodes of the surrounding area. However due to the depth of the micro-stratum it's likely to be the result of very light surface vegetation charring on the original land surface, which initiated the overlying organic accumulation and encouraged the high level of biological activity seen; this biological activity will have subsequently fractured the charcoal. The overlying organic accumulation is completely undisturbed with no indication of anthropogenic activity above or immediately surrounding the profile and like profile 4, indicates that the charring event was natural in origin.

Overall this has been a fluvially deposited sand, which is beginning to develop into a podzol but has had the past land surface lightly charred as a result of a natural forest fire episode. The profile has remained undisturbed since this light charring episode with no signs of physical disturbance or repeat burning which indicates that the organic accumulation was on going and did not require secondary burning episodes to re-stimulate organic accumulation and biological activity.

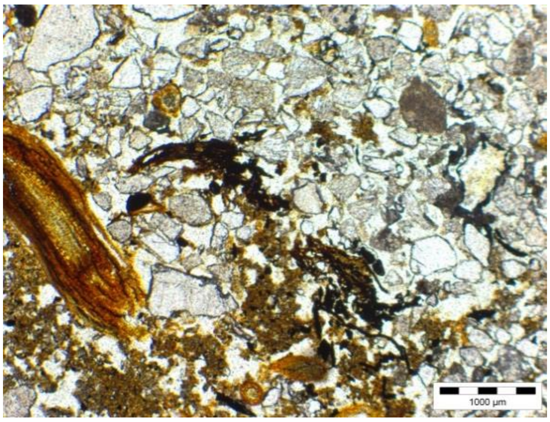


Figure 5.17: Overlapping boundaries between E-horizon and the overlying organic rich past land surface PPL x 2 mag

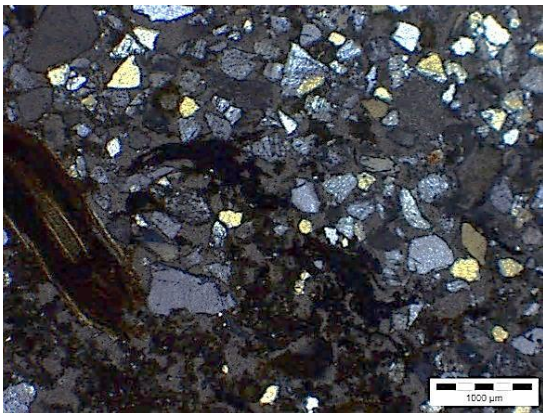


Figure 5.18: Overlapping boundaries between E-horizon and the overlying organic rich past land surface XPL x2 mag

5.2.4.6 Summary

Overall, this site has formed on and above fluvial deposited sands with the anthropogenically modified topsoils being formed from the upper level/s alongside the addition of turf and manure, and the hinterland sites beginning to podzolise. The hinterland samples were taken between this site and Prästsjödiket in order to act as control samples for both sites (due to their close proximity) and have both experienced light charring of the surface vegetation as a result of natural forest fires; see figure 5.20 for map showing location of all profiles across both sites.

The anthropogenic topsoils all overlie freely drained sands, which have led to the migration of fine mineral and organic material down through the underlying sands due to percolation. Profiles 1 and 3 show the preparation technique for this site whereby the surface vegetation is cleared, charred and mixed with turf and manure in order to establish a fertile cultural soil with turf and limited charcoal inputs continuing over time; the turf and manure fragments have completely decomposed indicating that the cultural soils are historic. Profile 1 has an extremely homogenised and worked microstructure, common phytoliths and diatoms within the turf and manure fragments indicate that it was the earliest established cultural soil studied, possibly the homefield, as the inputs included turf material from a wet environment befitting of the earlier flood periods. Profile 3 has been the latest established cultural soil out of those studied as the organic input has originated from a woody rather than wet environment indicating that the cultural land has spread out from the occupation area near the river (typically the favourable place to settle) into the surrounding woodland; profiles 2 and 3 are not as worked or developed as profile 1, indicating that they formed later and further away from the occupation area; cultural importance given to 'homefields'.

There have been no silt cappings at this site which, as they occurred very rarely at the neighbouring Prästsjödiket site, has been related to the fluvial origin of the soils rather than the climate being significantly milder; even though as a coastal site the climatic conditions will have been much milder than at the inland sites.

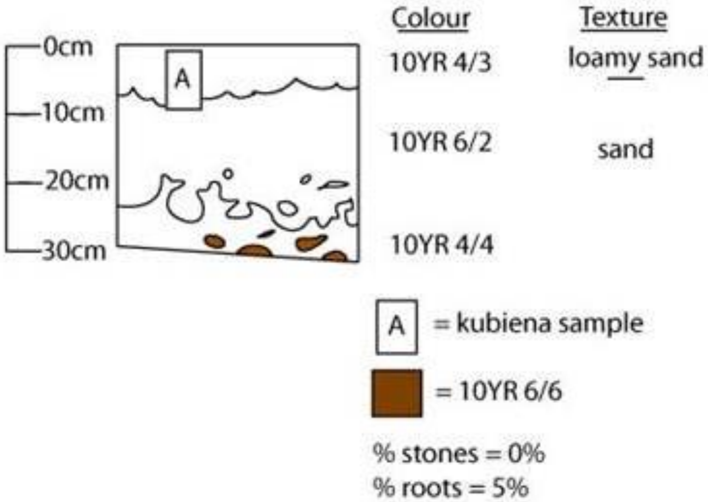


Figure 5.19: Photograph and soil profile diagram of profile 5

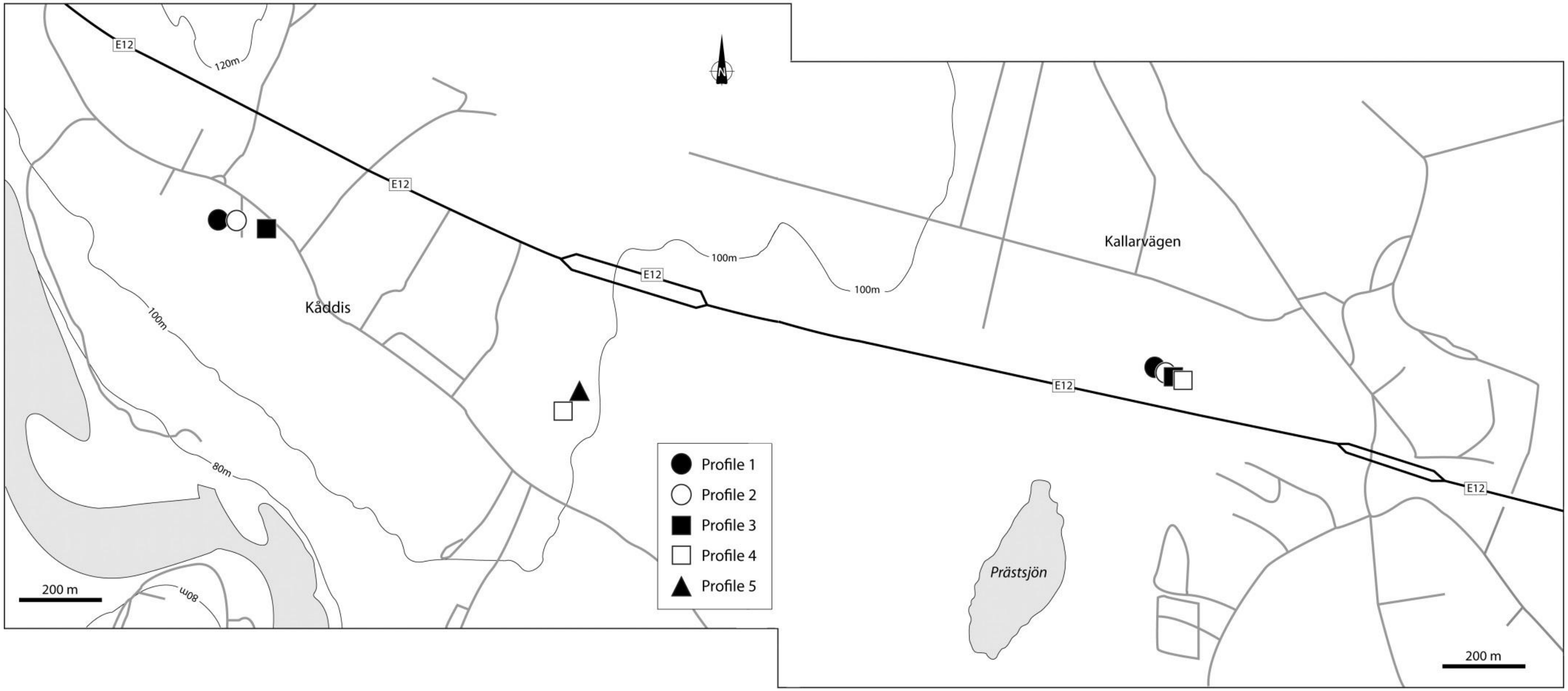


Figure 5.20: Location map showing all soil profiles for Kåddis (on left hand side) and Prästsjödiket (right hand side) with dual purpose control samples (profiles 4 + 5) located mid-way between the two sites

Table 5.2: Micromorphology description tables for Kåddis slides

				Coarse mineral material (>10µm)														Coarse Organic material (>10µm)								Fine Organic Material (<10µm)				Pedofeatures				Structure			
Profile	Micro-strata	Depth (cm)	Quartz %	Quartz maximum size	Feldspar %	Feldspar maximum size	Siltstone %	Siltstone maximum size	Mica %	Mica maximum size	Glauconite %	Arrangement of minerals	Fine mineral material (<60µm)	Silt coating frequency	Silt coating maximum size	Organic carbon coatings frequency	Organic carbon coating maximum	Organ residue	Tissue residue	Largest tissue residue (mm)	Lignified tissue	Sclerotia	% Charcoal	Largest charcoal	Cell residue	Amorphous black	Amorphous yellow	Amorphous brown	Amorphous red	Excremental (*Spheroidal*) 50-100µm	Fe impregnated mineral material %	Fe impregnated organic material %	% void space	Microstructure	Course material arrangement	Groundmass b fabric	C/F ratio
1A	1	15	25	2	20	2	10	2	2	1	t	SR	Grey + low IC	-	-	-	-	2	2	25 x 25	t	-	t	3	5	t	5	15	-	-	t	5	15	Weak pedality, granular	Well sorted + accommodated	Close porphyric, yellow brown SS	2/1
	2		25	3	20	3	10	3	10	1	t	SR	Grey + low IC	-	-	-	-	-	-	-	t	-	-	-	t	t	t	5	t	-	5	t	30	Single grain MS	Well sorted, un-accommodated	Close fine enaulic, brown SS	4/1
	3		5	1	-	-	-	-	2	1	-	SR	Grey + low IC	-	-	1	3	-	-	-	-	-	-	-	5	-	15	50	5	-	-	5	20	Weak pedality, crumb	Well sorted + accommodated	Open porphyric, orange SS	1/3
1B	1	40	30	1	10	1	t	1	20	1	-	R	Grey + low IC	-	-	-	-	-	-	-	t	-	-	-	10	2	5	t	t	-	t	t	20	Weak pedality, granular	Well sorted + accommodated	Close fine enaulic, grey-orange SS	3/1
	2		30	1	10	1	t	1	25	1	-	SR	Grey + low IC	-	-	-	-	-	-	-	t	-	-	-	t	t	15	10	5	-	40	t	5	Weak pedality, granular	Well sorted + accommodated	Close fine enaulic, grey-orange SS	3/1
	3		30	1	-	-	-	-	25	1	-	SR	Grey + low IC	-	-	-	-	-	t	50 x 50	t	-	-	-	10	2	10	2	t	-	t	-	15	Weak pedality, lenticular	Well sorted + accommodated	Open porphyric, grey SS	1/4
	4		25	2	20	2	20	2	10	1	-	SR	Grey + low IC	-	-	-	-	-	-	-	t	-	-	-	t	t	5	t	t	-	40	-	20	Weak pedality, crumb	Partially sorted & accommodated	Close fine enaulic, grey-orange SS	4/1

Note: Micro stratum 1 of slide 1A contains common phytoliths; located within turf material which represents 5% of the stratum

				Coarse mineral material (>10µm)														Coarse Organic material (>10µm)								Fine Organic Material (<10µm)				Pedofeatures				Structure			
Profile	Micro-strata	Depth (cm)	Quartz %	Quartz maximum size	Feldspar %	Feldspar maximum size	Siltstone %	Siltstone maximum size	Mica %	Mica maximum size	Glauconite %	Arrangement of minerals	Fine mineral material (<60µm)	Silt coating frequency	Silt coating maximum size	Organic carbon coatings frequency	Organic carbon coating maximum	Organ residue	Tissue residue	Largest tissue residue (mm)	Lignified tissue	Sclerotia	% Charcoal	Largest charcoal	Cell residue	Amorphous black	Amorphous yellow	Amorphous brown	Amorphous red	Excremental (*Spheroidal*) 50-100µm	Fe impregnated mineral material %	Fe impregnated organic material %	% void space	Microstructure	Course material arrangement	Groundmass b fabric	C/F ratio
	5		25	2	20	2	10	2	10	1	t	SR	Grey + low IC	-	-	-	-	-	-	-	-	-	-	-	5	t	10	5	t	-	t	t	15	Weak pedality, lenticular	Well sorted + accommodated	Double spaced porphyric, grey SS	1/6
	6		25	1	20	1	t	1	25	1	-	R	Grey + low IC	-	-	-	-	-	-	-	t	-	-	-	t	t	20	t	2	-	30	-	5	No pedality 'massive'	Well sorted + accommodated	Close porphyric, orange SS	2/1
2A	1	18	25	3	20	3	10	3	2	1	t	SR	Grey + low IC	-	-	1	3	2	2	100 x 50	t	-	t	1	t	2	5	10	5	t	5	-	20	Weak pedality, crumb	Partially sorted + well accommodated	Close porphyric, grey SS	3/1
	2		25	3	20	3	20	3	2	1	t	SR	Grey + low IC	-	-	-	-	-	-	-	t	-	-	-	t	t	2	5	t	-	5	-	20	Single grain MS	Partially sorted + accommodated	Coarse monic, grey SS	8/1
	3		25	2	20	2	10	2	t	1	-	SR	Grey + low IC	-	-	1	1	-	-	-	-	-	-	-	t	-	2	25	5	-	-	T	15	Weak pedality, crumb	Well sorted, partially accommodated	Close fine enaulic, brown SS	4/1
2B	1	40	25	3	25	3	20	3	5	2	t	R	Grey + low IC	-	-	1	5	-	t	250 x 150	t	-	-	-	t	t	t	t	t	-	10	-	20	Single grain MS	Well sorted, un-accommodated	Course monic, grey SS	10/1
3B	1	18	25	3	20	3	15	3	t	1	t	SR	Grey + low IC	-	-	2	5	-	t	100 x 50	t	-	t	4	t	t	5	5	t	-	15	T	30	Weak pedality, crumb	Partially sorted & accommodated	Close fine enaulic, grey-yellow SS	4/1

Note: Micro stratum 1 of slide 2A contains a trace of fractured phytoliths

			Coarse mineral material (>10µm)															Coarse Organic material (>10µm)								Fine Organic Material (<10µm)				Pedofeatures				Structure			
Profile	Micro-strata	Depth (cm)	Quartz %	Quartz maximum size	Feldspar %	Feldspar maximum size	Siltstone %	Siltstone maximum size	Mica %	Mica maximum size	Glauconite %	Arrangement of minerals	Fine mineral material (<60µm)	Silt coating frequency	Silt coating maximum size	Organic carbon coatings frequency	Organic carbon coating maximum	Organ residue	Tissue residue	Largest tissue residue (mm)	Lignified tissue	Sclerotia	% Charcoal	Largest charcoal	Cell residue	Amorphous black	Amorphous yellow	Amorphous brown	Amorphous red	Excremental (*Spheroidal*) 50-100µm	Fe impregnated mineral material %	Fe impregnated organic material %	% void space	Microstructure	Course material arrangement	Groundmass b fabric	C/F ratio
	2		20	3	20	3	15	3	2	1	t	R	Grey + low IC	-	-	3	5	-	-	-	t	3	-	-	t	15	t	t	-	-	20	T	25	Single grain MS	Partially sorted, un-accommodated	Coarse monic, grey SS	5/1
	3		10	2	t	1	-	1	t	1	-	R	Grey + low IC	-	-	2	5	-	2	300 x 200	30	24	5	6	5	15	10	5	5	-	t	T	10	Weak pedality, crumb	Partially sorted & accommodated	Close fine enaulic, yell-brown SS	4/1
4A	1	0	t	1	-	-	-	-	-	-	-	SR	Grey + low IC	-	-	2	2	5	10	150 x 50	t	-	-	-	10	t	5	10	t	-	-	10	30	Weak pedality, crumb	Partially sorted & accommodated	Double spaced fine enaulic. Un-differentiated B-fab	2/1
	2		25	2	20	2	15	2	t	1	t	SR	Grey + low IC	-	-	2	3	2	2	50 x 50	-	1	t	2	t	2	2	2	t	-	t	5	30	Single grain MS	Well sorted, un-accommodated	Coarse monic, grey SS	5/1
	3		20	2	20	2	5	2	t	1	-		Grey + low IC	-	-	2	2	t	-	-	-	-	25	6	t	10	t	t	t	-	t	T	20	Single grain MS	Partially sorted, un-accommodated	Coarse monic, grey SS	5/1
	4		20	2	10	2	10	2	t	1	-	SR	Grey + low IC	-	-	2	2	t	t	150 x 50	-	-	-	-	t	t	t	t	t	30	-	15	30	Weak pedality, crumb	Partially sorted, un-accommodated	Double spaced close enaulic. Un-differentiated B-fab	1/1
4B	1	5	5	2	-	-	-	-	-	-	-	SR	Grey + low IC	-	-	-	-	5	5	300 x 50	-	-	-	-	15	-	t	10	15	15	-	5	30	Weak pedality, crumb	Partially sorted, un-accommodated	Double spaced close enaulic, orange SS	2/1

				Coarse mineral material (>10µm)														Coarse Organic material (>10µm)								Fine Organic Material (<10µm)				Pedofeatures				Structure			
Profile	Micro-strata	Depth (cm)	Quartz %	Quartz maximum size	Feldspar %	Feldspar maximum size	Siltstone %	Siltstone maximum size	Mica %	Mica maximum size	Glauconite %	Arrangement of minerals	Fine mineral material (<60µm)	Silt coating frequency	Silt coating maximum size	Organic carbon coatings frequency	Organic carbon coating maximum	Organ residue	Tissue residue	Largest tissue residue (mm)	Lignified tissue	Sclerotia	% Charcoal	Largest charcoal	Cell residue	Amorphous black	Amorphous yellow	Amorphous brown	Amorphous red	Excremental *(Spheroidal)* 50-100µm	Fe impregnated mineral material %	Fe impregnated organic material %	% void space	Microstructure	Course material arrangement	Groundmass b fabric	C/F ratio
	2		25	3	10	3	10	2	t	2	t	SR	Grey + low IC	-	-	1	3	5	2	50 x 50	-	-	-	-	10	t	2	t	t	t	20	5	30	Single grain MS	Well sorted, un-accommodated	Course monic, grey SS	5/1
5A	1	1	t	1	-	-	-	-	-	-	-	SR	Grey + low IC	-	-	-	-	15	15	250 x 100	t	-	-	-	20	t	5	10	5	15	-	T	15	Weak pedality, granular	Partially sorted & accommodated	Close fine enaulic, un-differentiated B-fabric	1/2
	2		2	1	-	-	-	-	-	-	-	SR	Grey + low IC	-	-	1	3	5	5	150 x 100	-	-	t	3	10	10	5	5	5	30	-	5	25	Weak pedality, granular	Partially sorted & accommodated	Close fine enaulic, un-differentiated B-fabric	1/1
	3		20	3	5	2	10	1	t	1	-	SR	Grey + low IC	-	-	1	2	5	5	250 x 50	t	-	-	-	t	5	t	t	10	15	t	15	25	Weak pedality, crumb	Well sorted, partially accommodated	Close fine enaulic, grey SS	4/1

5.2.5 Chemical analysis

5.2.5.1 pH

The pH values for Kåddis contradict the pattern seen in the Sámi samples in that the pH does not always increase with depth; profiles 4 and 5 are control sample and show the afore mentioned decreases in acidity with depth seen in the podzol soils at the Sámi sites. This indicates that the amendment of the topsoil to an anthropogenic cultural soil significantly decreases the acidity of the topsoil; see figure 5.21.

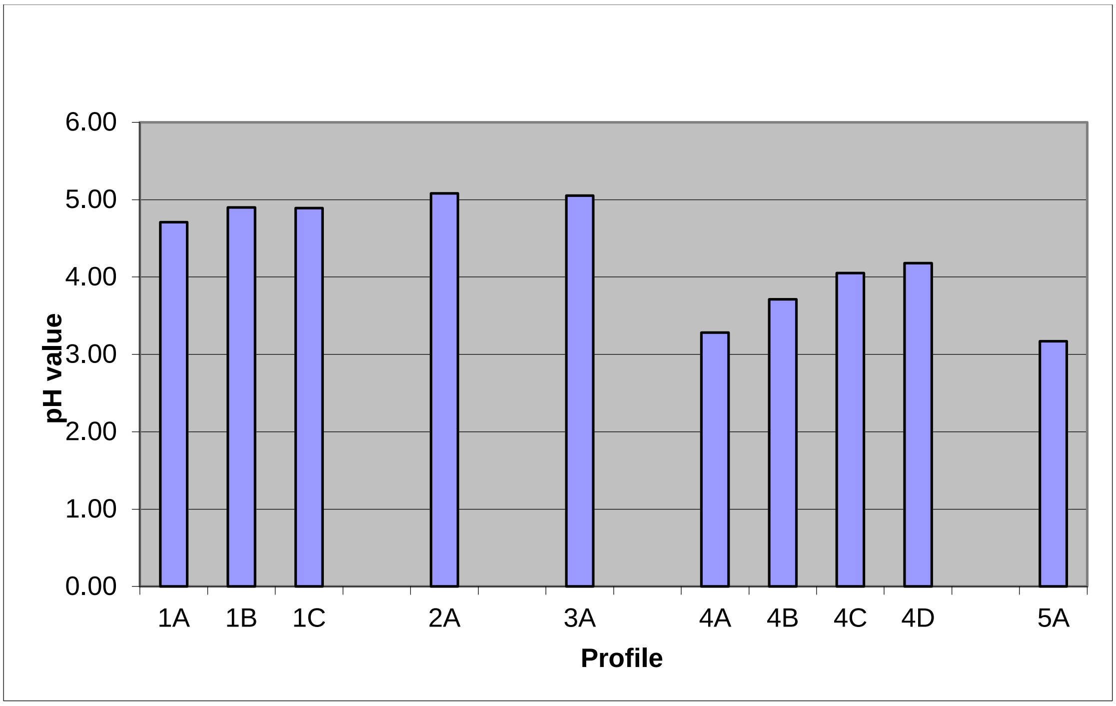


Figure 5.21: Bar graph showing the pH values for all profiles at Kåddis

5.2.5.2 Magnetic susceptibility

The magnetic susceptibility values for Kåddis are all relatively low with sample 4D returning a negative value (see figure 5.22). Profile 4 is a control sample taken from an undisturbed podzol whereas samples 1 – 3 are all from anthropogenically enhanced soil profiles. This indicates that there is an elevation in the magnetic value of the anthropogenically amended soils however it is not enough support it as a reliable cultural indicator for European activity.

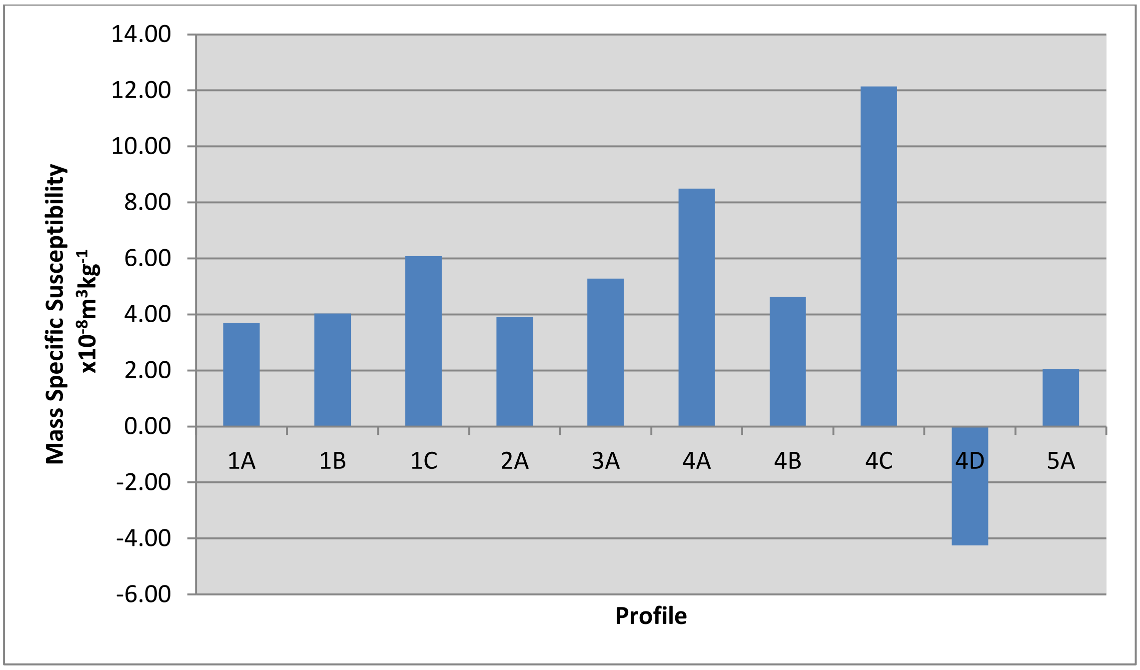


Figure 5.22: Mass Specific Magnetic Susceptibility values for Kåddis

5.2.5.3 SEM analysis

A scanning Electron Microscope (SEM) was used to chemically measure each micro-strata so that a range of elements could be statistically analysed. The full list of outputs from the ANOVA can be found in the appendixes but the statistically significant relationships, at a 95% probability, have been listed and discussed here.

The bulk of the elemental concentration was carbon, oxygen and silicon which are key components of the local mineralogy, as well as the resin used in the production of the thin section slides, so these were removed from all analysis as were sulphur and nickel which were only rarely picked up; the % concentration of the remaining elements is below 3% apiece. Nitrogen, sulphur and manganese were not normally distributed due to their low frequency within the samples and as such have not been calculated.

One way ANOVA's were carried out comparing each soil horizon from each of the three sites. The phosphorous levels in the anthropogenic topsoil's at the three sites were statistically distinct from one another (see figure 5.23). As the base soil at each site is podzolic this spread in values is most likely linked to the land management techniques employed at each site i.e. the applied materials.

```
Source  DF      SS      MS      F      P
Site     6  1.2490  0.2082  11.85  0.000
Error   20  0.3515  0.0176
Total   26  1.6005

S = 0.1326   R-Sq = 78.04%   R-Sq(adj) = 71.45%

                           Individual 95% CIs For Mean Based on
                           Pooled StDev
Level        N    Mean   StDev  ---------+---------+---------+---------+
Hornmyr      9  0.0578  0.0335          (--*--)
Gammelhemmet 6  0.3400  0.2425                   (--*---)
Kåddis       3  0.6700  0.1500                            (----*-----)
                                ---------+---------+---------+---------+
                                      0.00      0.30      0.60      0.90
```

Figure 5.23: Output from Tukey's multiple comparisons regarding the Phosphorous levels in the topsoil at Hornmyr, Gammelhemmet and Kåddis

The analysis of the E-horizon returned significant differences between the titanium and chloride levels at Kåddis from the other European sites (see figures 5.24 and 5.25 respectively). This may be related to the difference in the soils between the inland sites (Hornmyr and Gammelhemmet) and the near coastal site of Kåddis in that although all three sites have anthropogenically enhanced topsoil's overlying podzolic soils the inland profiles are well developed podzols whereas the coastal profiles were weakly developed podzols overlying deep sand deposits. The sands at Kåddis have been shown, from the micromorphological analysis, to be freely draining to the point where the increased percolation rates are enhancing the natural podsolization process which explains the difference in the titanium levels from the topsoil to the E-horizon, as well as from the inland sites; the difference in the titanium level is also seen in the B-horizon (see figure 5.26). The difference in the potassium levels in the B-horizon can also be related to this (see figure 5.27). However as touched on within the Sámi landscape chapter the chloride levels in the E-horizon are most likely the result of humification of organic material (Keppler and Biester 2003) and the titanium peaks could indicate anthropogenic activity but are unreliable in this case; titanium peaks have been correlated to anthropogenic activity in the form of exposed soil and soil erosion but this cannot be confirmed in either case due to the link between fires and increased titanium levels (Görres and Frenzel 1997; Hölzer and Hölzer 1998).

```
Source   DF       SS       MS     F      P
Site      6  0.03649  0.00608  3.98  0.004
Error    34  0.05202  0.00153
Total    40  0.08851

S = 0.03911   R-Sq = 41.23%   R-Sq(adj) = 30.86%

                              Individual 95% CIs For Mean Based on Pooled StDev
Level        N     Mean    StDev  ---------+---------+---------+---------+
Hornmyr      6  0.09167  0.03764                      (-----*------)
Gammelhemmet 6  0.10000  0.01265                        (-----*-----)
Kåddis       3  0.00000  0.00000  (---------*---------)
                                  ---------+---------+---------+---------+
```

Figure 5.24: Output from Tukey's multiple comparisons regarding the Titanium levels in the E horizon at Hornmyr, Gammelhemmet and Kåddis

```
Source   DF        SS        MS     F      P
Site      6  0.016777  0.002796  8.10  0.000
Error    34  0.011736  0.000345
Total    40  0.028512

S = 0.01858   R-Sq = 58.84%   R-Sq(adj) = 51.58%

                              Individual 95% CIs For Mean Based on Pooled StDev
Level        N     Mean    StDev  ---------+---------+---------+---------+
Hornmyr      6  0.01000  0.01673        (-----*-----)
Gammelhemmet 6  0.00333  0.00816     (-----*-----)
Kåddis       3  0.05333  0.02517                        (--------*--------)
                                  ---------+---------+---------+---------+
                                       0.000     0.025     0.050     0.075
```

Figure 5.25: Output from Tukey's multiple comparisons regarding the Chloride levels in the E horizon at Hornmyr, Gammelhemmet and Kåddis

```
Source   DF        SS        MS     F      P
Site      5  0.019691  0.003938  6.44  0.001
Error    21  0.012850  0.000612
Total    26  0.032541

S = 0.02474   R-Sq = 60.51%   R-Sq(adj) = 51.11%

                              Individual 95% CIs For Mean Based on
                              Pooled StDev
Level        N     Mean    StDev  ---+---------+---------+---------+------
Hornmyr      4  0.06000  0.04082            (-----*-----)
Gammelhemmet 6  0.07833  0.01941                 (-----*----)
Kaddis       4  0.01500  0.03000  (------*-----)
                                  ---+---------+---------+---------+------
                                   0.000     0.040     0.080     0.120
```

Figure 5.26: Output from Tukey's multiple comparisons regarding the Titanium levels in the B horizon at Hornmyr, Gammelhemmet and Kåddis

```
Source  DF      SS      MS     F      P
Site     5  0.4305  0.0861  4.45  0.006
Error   21  0.4064  0.0194
Total   26  0.8369

S = 0.1391   R-Sq = 51.44%   R-Sq(adj) = 39.88%

                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Level         N    Mean   StDev  --------+---------+---------+---------+-
Hornmyr       4  0.4275  0.0512    (------*-------)
Gammelhemmet  6  0.5133  0.1341          (-----*-----)
Kåddis        4  0.7675  0.0732                    (------*-------)
                                 --------+---------+---------+---------+-
                                      0.40      0.60      0.80      1.00
```

Figure 5.27: Output from Tukey's multiple comparisons regarding the Potassium levels in the B horizon at Hornmyr, Gammelhemmet and Kåddis

5.2.6 Summary

The analysis has revealed that the site has been prone to flooding periods which continued into the early stages of occupation; the rounded multi-layer sand deposits indicate the flood periods and the diatoms in the organic material indicate a wet environment. The anthropogenically amended topsoils (in profiles 1-3) show evidence of plaggen style cultivation, with the input of organic and mineral materials. This addition of material has led to a decrease in acidity when compared to the natural soil (checked against the control samples) and an increase in the phosphorous level. The significant difference in the chloride and titanium levels when compared to the other European sites is further indication of the sand deposits underlying the site. The homogenous nature of the topsoil indicates the high level of working that the soil has experienced however this decreases with increasing distance from the site indicating that the field systems were expanded slowly and/or that efforts, i.e. inputted materials, were concentrated on the 'home-field'.

Although several of the traditional cultural indicators, such as charcoal, have been translocated and/or dissolved the distinct changes to the soil structure is indicative of a heavily worked arable soil. The increased depth of the anthropogenic topsoil is evident from the field analysis, the decreased acidity in comparison to the undisturbed podzol topsoil from the pH values, the peak in phosphorous from the chemical analysis and the structural changes and added materials from the micromorphological analysis. The 'added' materials included charred organic material, turf material and manure with the continued, intensive reworking of the soil leading to a highly amorphous, homogenised micro structure.

5.3 Gammelhemmet

5.3.1 Background

Gammelhemmet is situated on intermediate intrusive bedrock and podzol soils (Swedish Geological Society, 2010). It was settled in AD1701 along with the construction of a water powered mill within walking distance of the site (Länsstyrelsen/Skogsmuseet, 1999). Gammelhemmet was nevertheless abandoned after 100 years of occupation due to the severely frosty conditions on site, which may have reduced the pore space in the soil leading to a pan forming and subsequent water logging, with the inhabitants relocating 2.5km North East and settling the village of Knaften (Länsstyrelsen/Skogsmuseet, 1999).

The original Gammelhemmet village has been partially reconstructed and includes several reconstructed wooden buildings and a reconstructed watermill further upstream; the vegetation around the reconstructed buildings is open grassland with some pine trees (see figures 5.28 and 5.29 for photograph of reconstructed building and mill respectively.

Figure 5.28: Photograph showing reconstructed building at site

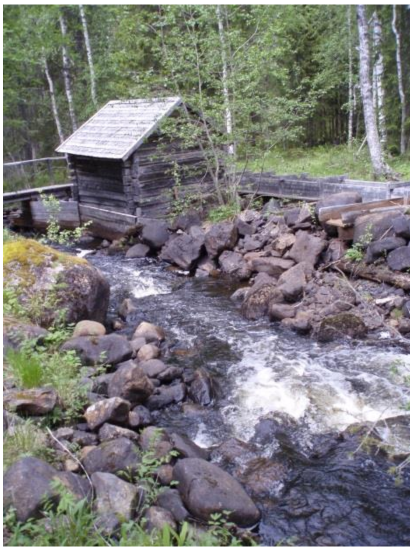


Figure 5.29: Photograph showing reconstructed water mill

5.3.2 Study locations

Profile one was situated just off of this open grassland in an area full of small clearance stone cairns; all profile locations are mapped in figure 5.30 with an accompanying satellite image in figure 5.31. It is a podzol soil with an interrupted albic horizon but there does not appear to be any other amendments that have affected the podzol. An anthric topsoil overlies the podzol and fits with the FAO's plaggen criteria but is shallower than the plaggen type anthric topsoil at Hornmyr; this will be due to the site being abandoned after a 100 years.

Profile two was also situated in an area of clearance cairns, further along than profile one. It has a shallower anthric topsoil than profile one but no albic horizon, which could possibly indicate that the soil had been ploughed and that profile 1 had been used more intensively, perhaps as the main field.

Profile three was situated in a mixed pine and birch wood located to the back of the first two profiles. It is a podzol with well-developed albic and spodic horizons but with no anthric topsoil, indicating that it has never been used for cultivation and will therefore be a suitable control for the other profiles; the podzol has been distorted, possibly due to freeze/thaw action.

Profile four was dug where the original home-field was thought to be and is known as Johnson's acre (Länsstyrelsen/Skogsmuseet, 1999). This area has recently had pine trees cleared from it and the trunks are still *in situ*, which could have disturbed the underlying soil; the profile was dug in-between a group of trunks to minimise any potential disturbance. The profile contained charcoal rich anthric topsoil with an incomplete albic horizon; the albic horizon material and overlying topsoil are at an angle which fits the shape of a plough/ard blade and is a confirmation of ploughing (see figures 5.30 and 5.31 for photographs). The anthric topsoil also appeared to have a very thin second albic horizon indicating that the soil had begun to re-podzolise after abandonment.

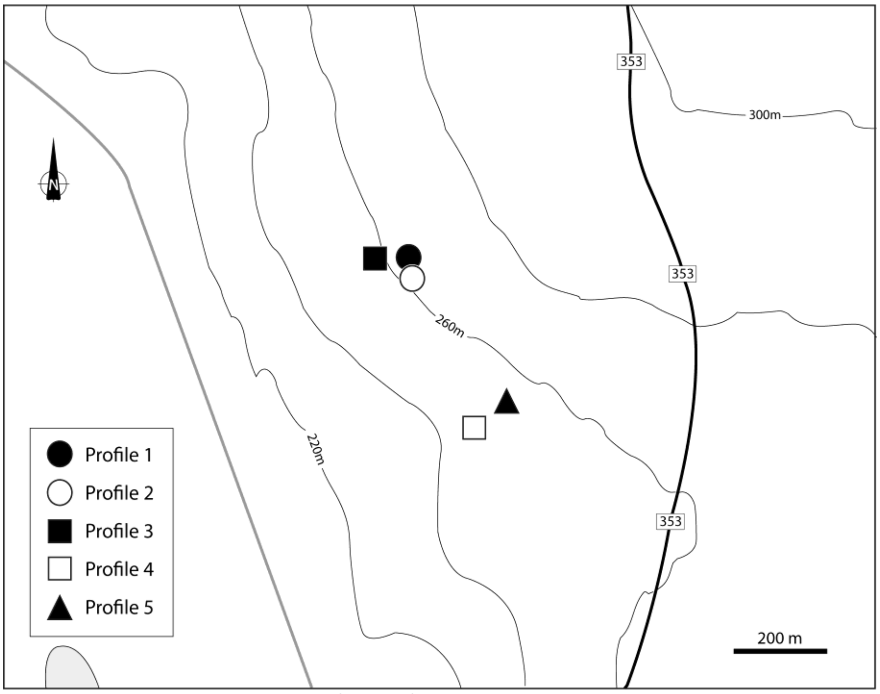


Figure 5.30: Map showing location of all profiles within the Gammelhemmet site

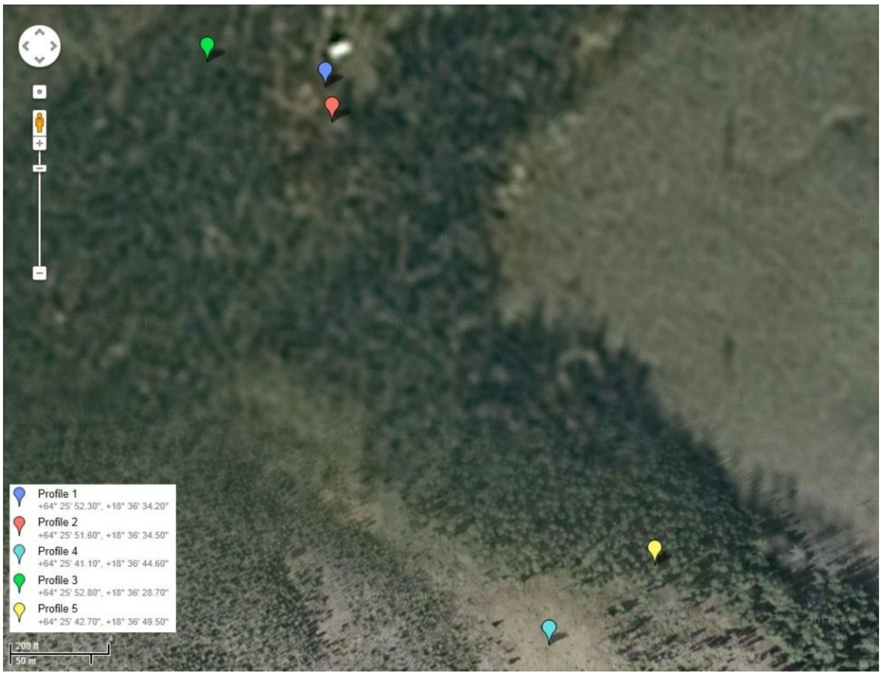


Figure 5.31: Screen grab of the Google satellite image showing profile locations (Google Maps, 2013)

Profile five was located in pine woodland adjacent to profile four. It revealed a well-developed podzol with undulating albic and spodic horizons which were overlain by a charcoal rich stratum.

Figure 5.32: Photograph of profile 4 at Gammelhemmet

Figure 5.33: Annotated photograph of profile 4 at Gammelhemmet highlighting plough/ard mark in profile

5.3.3 Chronology

Gammelhemmet was occupied from AD 1701-1801 with three out of the five profiles in the transect showing anthropogenic topsoils overlying mixed and/or disturbed podzols. Profile 1 shows a visibly mixed B and E horizon which is overlain by an anthropogenic topsoil; see table 5.3 for full sample information and figure 5.34 for radiocarbon plot, sample location is marked on the digitised soil profiles in figures 5.37 and 5.44. Sample A was taken from the disturbed E-horizon and was dated to AD1328-1445, pre-dating the settlement period. Sample B was taken from the anthropogenic topsoil and, was dated to AD1493-1792, which covers the occupation period. This indicates that the natural charring of the area was historic with the charcoal having migrated down into the E-horizon, giving a strong probability that either a secondary charring event occurred as part of the preparation for cultivation and/or that charred organic material had been applied/added to the topsoil as part of an on-going land management technique.

Profile 4 is believed to be the original home-field and has a deeper anthropogenic topsoil than the previous profiles as well as visual evidence of cultivation in the form of a plough/ard mark within the profile; see table 5.3 for full sample information and figure 5.26 for radiocarbon plot. Sample A was taken from a visible patch of charred material within the anthropogenic topsoil and has been dated to AD1482-1646. This date fits with sample 1A and indicates a phase rather than a singular localised burning event. As profile 1's earlier phase pre-dates the occupation period it suggests a natural forest fire event, the charred material may then have been mixed into the overlying anthropogenic topsoil as either part of the preparation of the topsoil and/or through the on-going mixing from ploughing. The later date could again indicate a secondary natural forest fire but as it encompasses the occupation period it could also be indicative of a slash and burn style of clearance and/or the application of charred organic material as part of a plaggen style of soil management.

Table 5.3: Table containing information on location, type and age of all radiocarbon dated material from Gammelhemmet

Site reference	Sample reference	Depth of sample (cm)	Lab code	Material	Radiocarbon Age BP	Calibrated Date (≥95.4%)
Gammelhemmet	Sample 1A	19	26887 (GU20382)	Pinus sylvestris	510±35	AD 1328-1445
Gammelhemmet	Sample 1B	9	26891 (GU20383)	Pinus sylvestris	285±30	AD 1493-1792
Gammelhemmet	Sample 4A	0	26892 (GU20384)	Pinus sylvestris	320±30	AD 1482-1646

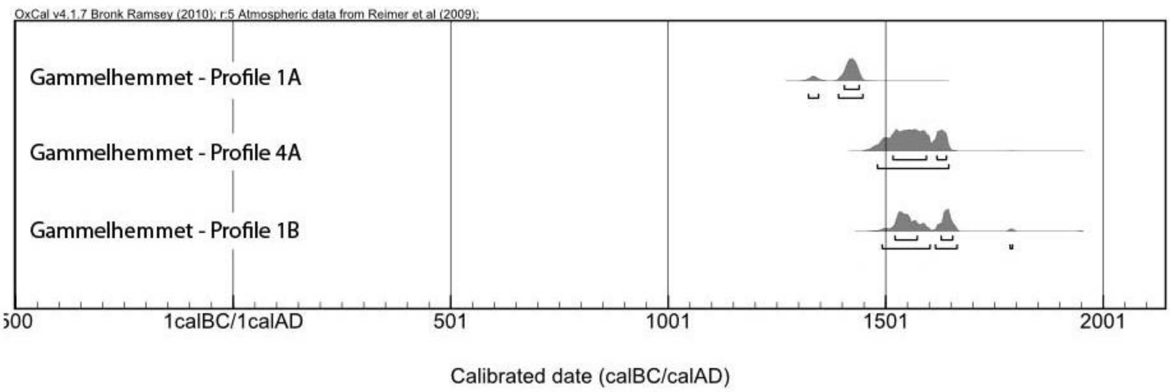


Figure 5.34: Radiocarbon plots showing the calibrated dates for the four samples dated from Gammelhemmet

5.3.4 Micromorphology

5.3.4.1 Profile 1

5.3.4.1.1 Description

Slide 1C was taken at a depth of 40cm; see figure 5.37 for soil profile drawing and location of slide and table 5.4 for the micromorphology description tables. Only a trace of the mineral material is iron stained and the total organic content of the slide is 10% (5% cell residue, 5% black amorphous organic). The highly altered anorthoclase grains seen in the lower strata at Hornmyr, in addition to where they had been added to the upper anthropogenic strata, are common. The large periglacial silt capping's (size 5) associated with similar strata at Hornmyr are also common here.

Slide 1B was taken at a depth of 20cm and incorporates the upper B-horizon and lower E-horizon. The B- horizon has coarse grained mineral material (up to size 5) which is iron stained (25%) and very few size 1 silt capping's. There is also the organic root type material, seen in the B-horizons of other sites (10% coarse organic material), and a very high number of punctuations (10% of slide black amorphous organic) not seen elsewhere; see figures 5.35 and 5.36 for photographs.

The E-horizon has been split into two micro-strata, the lower more compact stratum which has very few size 1 silt capping's and the upper charcoal rich stratum, which has no silt capping's. The lower micro-stratum has a trace of charcoal, is very compact. The highly compact nature of the micro-stratum is related to the abundance of fine mineral material. The upper E-horizon material is similar in form but with larger, more developed pore spaces and a higher concentration of ferruginised charcoal (10%).

Slide 1A was taken at a depth of 5cm and incorporates B-horizon material and anthropogenic topsoil material; the B-horizon material has the same morphology and elements as the B-horizon material seen in slide 1B with very few, size 2 silt capping's. The anthropogenic topsoil includes B-horizon material, the original A-horizon and charred organic material. It has been split into three discreet micro-strata to aid discussion (listed in the description table as strata 1-3). The lower micro-stratum is still rich in B-horizon material and shares the size 2 silt capping's seen lower in the profile (rare) alongside rare size 1 carbon coatings and a 2% charcoal from the overlying charred material. The central stratum is defined by its higher charcoal percentage when compared to the other strata. The upper anthropogenic micro-stratum is organic rich with a very high concentration of spheroidal excremental material (25%) and size 1 silt and carbon capping's (very rare and rare respectively).

5.3.4.1.2 Interpretation

The bleached nature of the mineral material (only a trace of iron staining and low organic percentage) in slide 1C is indicative of a podzols E-horizon, however the granular microstructure and large mineral grain size (up to size 5) is indicative of C-horizon material. This is most likely due to the depth of the material in that the material moving down profile from the eluviation processes is deposited in the upper B-horizon as part of the corresponding illuviation process. As this slide was taken from the deep-B, upper C-horizon the lack of organic material and iron staining is related to the distance between the sample and the inputted and eluviated organic and iron material.

Slide 1B incorporates the upper B and lower E-horizons. The B-horizon here is very similar in morphology to others seen at other sites with the exclusion of the high number of punctuations present (10% of the black amorphous material). As organic punctuations can form and be found in various soil types from various activities so it is unclear as to why there is an accumulation of them here. With the evident eluviation processes in the profile it is possible that the punctuations have moved down profile from a higher stratum, perhaps originating as charred material. The E-horizon has a weakly developed lenticular microstructure which has been exaggerated through frost action. The horizon can be split into two strata which are differentiated by their compactness. The lower strata is more compact indicating that it has been subject to more freeze thaw action than the upper, perhaps having been part of the permafrost layer historically; the continual freezing and thawing of material causes the soil to expand and contract, reducing pore space and increasing compaction levels. The compaction can also be linked to the high level of fine mineral material as the fine material will have filled the pore spaces as it eluviated down profile. The upper E-horizon also has a higher percentage of ferruginised charcoal. This indicates that the charcoal is migrating down profile from the overlying charred strata and has not reached the lower depths of the E-horizon; it will be difficult to percolate into the lower E-horizon due to its compact nature.

Slide 1A incorporates the anthropogenically modified topsoil and mineral material which is reminiscent of the B-horizon material; it has the same morphology and elements as the B-horizon material seen in slide 1B with no visible boundary between it and the overlying anthropogenic topsoil. This indicates that the B-horizon material has been added from elsewhere in the site. This is supported by the inclusion of very few, size 2 silt capping's which are typical of deeper soil horizons and are in this instance displaced.

The anthropogenic topsoil is a mixture of the added B-horizon material, original A-horizon and charred organic material and has been split into three discreet micro-strata (listed in the description table as strata 1-3) which are defined by the amount of charcoal and void space present as well as the mineral grain sizes. The lower micro-stratum is rich in the displaced B-horizon material, including the associated silt cappings, but also includes 2% charred material. The higher charcoal inclusion and larger mineral grain sizes in the central anthropogenic micro-stratum indicates that the charred material was added after the initial stages of preparation alongside additional mineral material; very few size 3 organic carbon coatings present. The upper stratum is defined by its organic concentration and the corresponding high level of biological activity. The spheroidal excremental material (25%) is not present in any of the lower micro-strata and indicates, alongside the increased level of porosity and reduction in mineral grain size, a change in land use i.e. mineral material is no longer being added to the profile and ploughing/cultivation has ceased. The inclusion of size 1 silt and carbon coatings indicates that although the input of externally sourced mineral and charcoal material has ceased, the increased level in biological activity has resulted in a light mixing of the top two micro-strata.

Overall it appears that the site has been podzolic in origin and has been prepared for cultivation by mixing the charred and E-horizon material, before B-horizon material from elsewhere in the site was added and mixed with added organic material. The 10% charcoal level in micro-strata 2 of slide A indicates new inputs of charred organic material which has been added at a later, but still early, stage; the 2% charcoal in micro-strata 3 and trace in the B-horizon are indicative of migrating charcoal due to percolation. The reduction in compaction with increasing proximity to the surface and indicates intensive cultivation during the initial use of the profile. The high level of spheroidal excremental material (25%) and increased level of porosity in the upper anthropogenic stratum indicates a change in land use management and most likely indicates the abandonment of this profile.

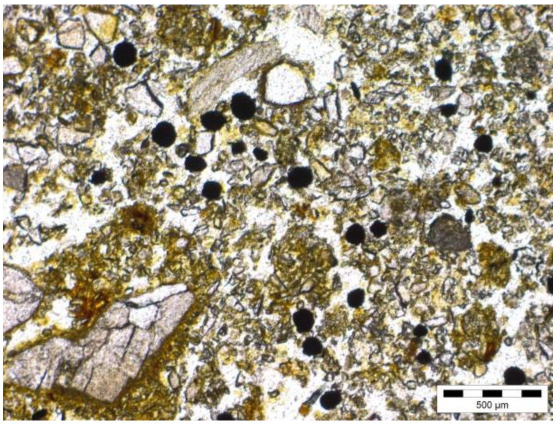


Figure 5.35: Organic punctuations PPL x4 mag

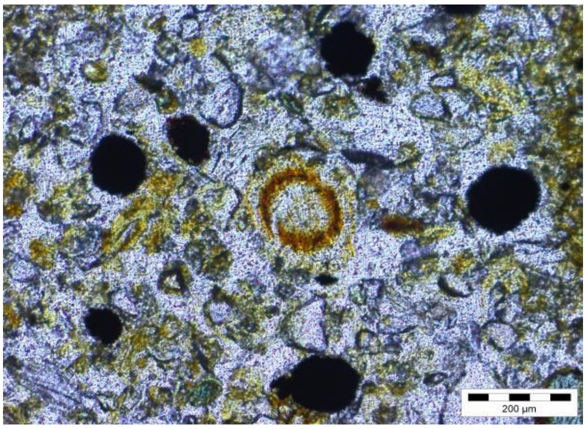


Figure 5.36: Organic punctuations close up PPL x10 mag

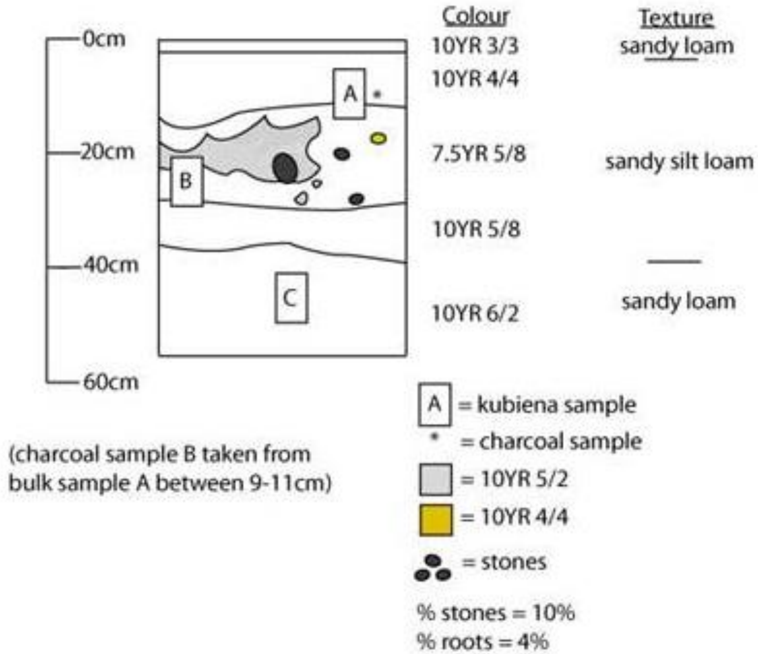


Figure 5.37: Photograph and soil profile diagram of profile 1

5.3.4.2 Profile 2

5.3.4.2.1 Description

Slide 2A was taken at a depth of 6cm; see figure 5.40 for soil profile drawing and location of slide and table 5.4 for the micromorphology description tables. Both strata have similar mineral grain sizes and the same level of iron staining (10% of mineral material) with very large silt capping's (very few size 4 in lower stratum and size 5 common in upper stratum) and size 2 organic carbon coatings (very few in lower stratum and common in upper); see figure 5.38 for photograph of iron stained silt capping. The upper micro-stratum is however more coarse grained overall with a coarse to fine ratio of 4/1 (compared to 3/1 in lower) with the common, very large silt capping's and the slightly more open and less developed microstructure. The increased organic content in the upper stratum (42% vs. 26% in lower stratum), which includes a 2% charcoal input, can be seen visibly (upper stratum is darker brown) and has resulted in a more A-horizon type microstructure. Turf fragments are also visible within the stratum (see figure 5.39 for photograph of deeply humified and amorphous turf material).

5.3.4.2.2 Interpretation

Slide 2A incorporates both B-horizon type material, identified through its structure and the presence of silt capping's and iron stained mineral grains, and anthropogenically modified topsoil material. The B-horizon material is evident as two strata which are very similar in composition but with the upper having a higher coarse to fine ratio. The very large silt capping's within the higher stratum go against the typical reduction in capping size with proximity to the surface, indicating that, alongside the coarser nature of the material, the upper strata includes mineral material derived from elsewhere in the site. The more open, less developed microstructure supports this view as it indicates mixing. The higher level of organic material and presence of turf fragments within the upper stratum indicates an input of organic material and/or due to the mixed nature of the soil that the original topsoil has been mixed with the inputted B-horizon material. Therefore the upper stratum consists of externally sourced B-horizon material which has been mixed into the existing soil as part of the preparation for cultivation.

Overall this profile is similar to profile one in that it has been a podzol prior to being amended, however the E-horizon is no longer visible, indicating that it has been mixed into the anthropogenic topsoil's; there is evidence of mixing between the B and A horizons but no pockets of E-horizon material are present, indicating that the soil has been well mixed. There is evidence of the addition of mineral and organic material, B-horizon material and turf fragments respectively, which follows the same amendment pattern seen in profile 1 however the anthropogenic topsoil is much shallower, indicating that the soil was developed later or used less intensively.

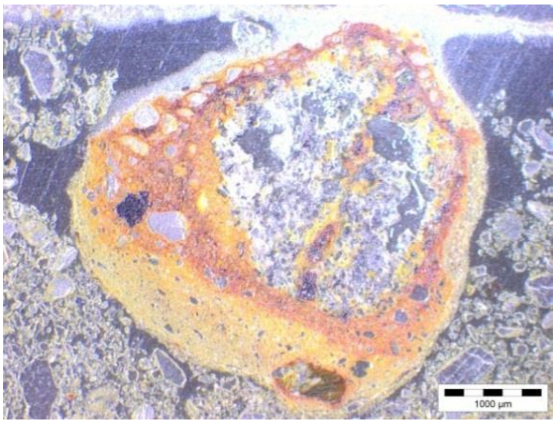


Figure 5.38: Iron stained silt capping OIL x2 mag

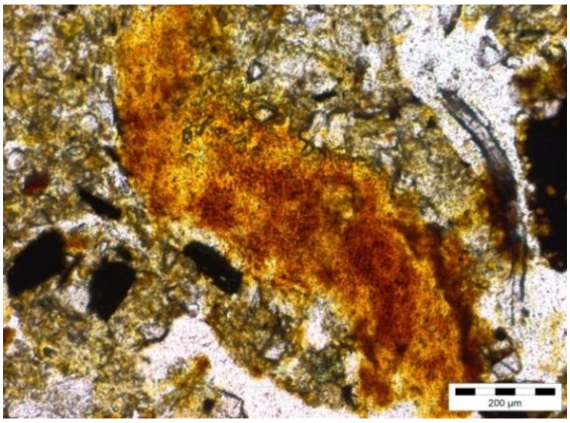


Figure 5.39: Highly amorphous turf fragment in anthropogenically enhanced soil PPL x10 mag

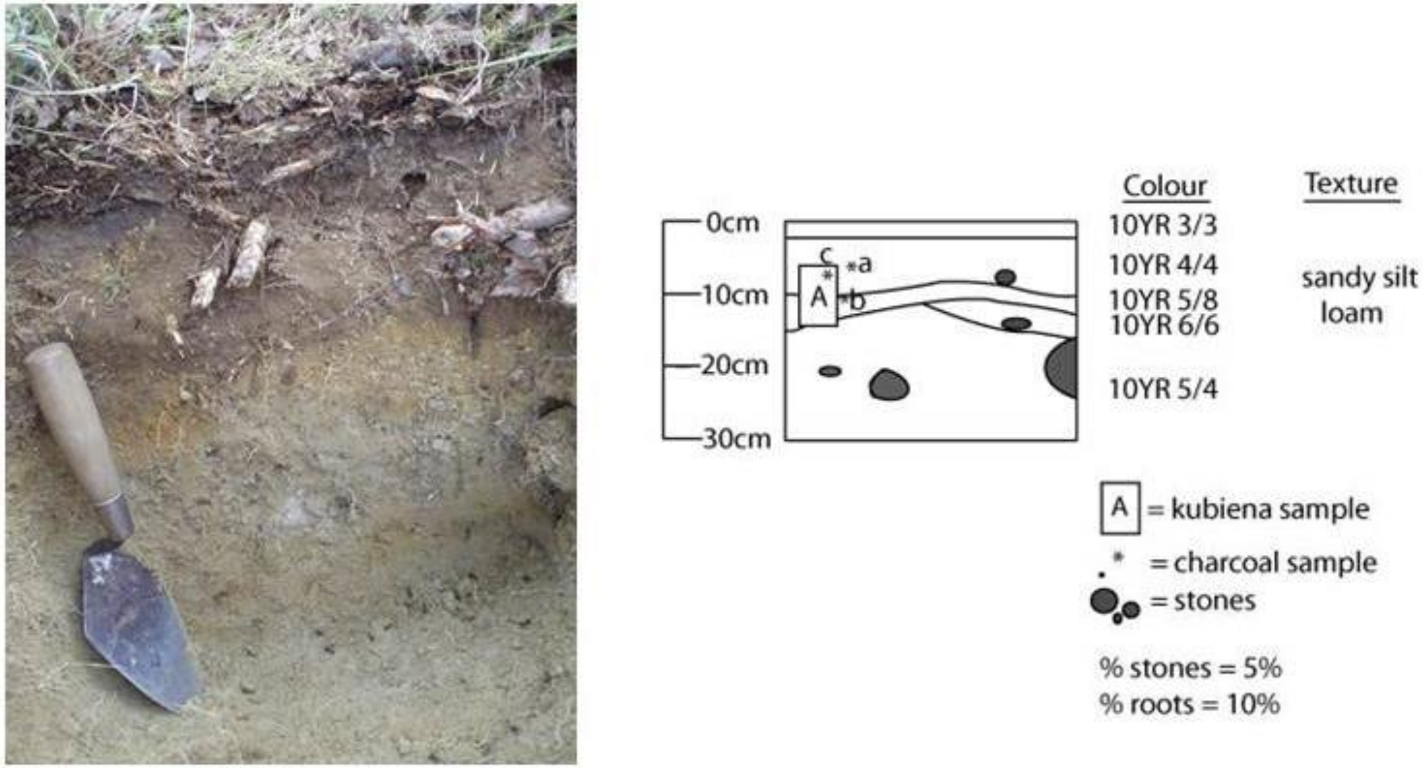


Figure 5.40: Photograph and soil profile diagram of profile 2

5.3.4.3 Profile 3

5.3.4.3.1 Description

Slide 3B was taken at a depth of 25cm; see figure 5.41 for soil profile drawing and location of slide and table 5.4 for the micromorphology description tables. The material is very compact with 10-15% pore space and a weak lenticular microstructure and an abundance of fine mineral material as seen in slide 1B. Size band 1 silt capping's are common with very few organic carbon coating near the top of the slide.

Slide 3A was taken at a depth of 0cm and incorporates the upper B-horizon, the E-horizon and a trace of the A-horizon in the upper left of the slide. The B-horizon material is strongly iron stained (30% of mineral material stained) with size 1 silt capping's (common) and is rich in organic material (40%).

The E-horizon material has very few organic carbon coatings (size 2), a trace of charcoal and 10% black amorphous organic material which will have a degree of dissolved charcoal present within it. The very thin organic accumulation present in the upper left of the slide is the present organic A-horizon and shows biological activity.

5.3.4.3.2 Interpretation

Slide 3B incorporates the C-horizon. This is similar to the C-horizon material seen in profile 1 but as it is shallower it appears as a mixture of B and E-horizon material through the inclusion of lenticular voids and iron free mineral grains, typical of an E-horizon, set within the iron rich microstructure which is typical of a B-horizon. The material is compact which indicates a high level of freeze thaw activity. A high percentage of fine mineral material is present, as seen in profile 1, which indicates that although the similar material seen in slide 1B was iron depleted (trace of iron staining) that it may have originated from deep within an externally sourced profile and has simply not had the time to repodzolise. The silt and carbon coatings are consistent with undisturbed soils in the area indicating that there has been no amendment to the lower strata of this profile.

Slide 3A incorporates the upper B-horizon, E-horizon and the thin A-horizon. The B-horizon material is similar to that seen in the Sámi and control samples and shows no signs of disturbance, indicating that the stratum has not been subject to anthropogenic amendment; there are very few size 1 organic carbon coatings present which indicates the possibility of light disturbance higher up in the profile. The trace of charcoal and 10% black amorphous material within the E-horizon indicates that as the charcoal is so small is size (size band 1) with no signs of organic accumulation, that a light to medium burning episode has occurred nearby and these fragments have been deposited by aeolian processes; as the charcoal fragments have already started moving down profile it suggests that the burning episode was historic. The overlying thin organic accumulation has been subject to biological activity and supports the theory of the organic accumulation and high level of biological activity in the upper stratum of profile 1 being the result of abandonment.

Overall profile 3 is natural. The lenticular microstructure in slide 3B and in the E-horizon of slide 3A is well developed and indicates that there has been no physical disturbance to the site. The trace of size 1 charcoal indicates that anthropogenic activity has been occurring within the vicinity but the lack of disturbance shows that it never happened directly upon it.

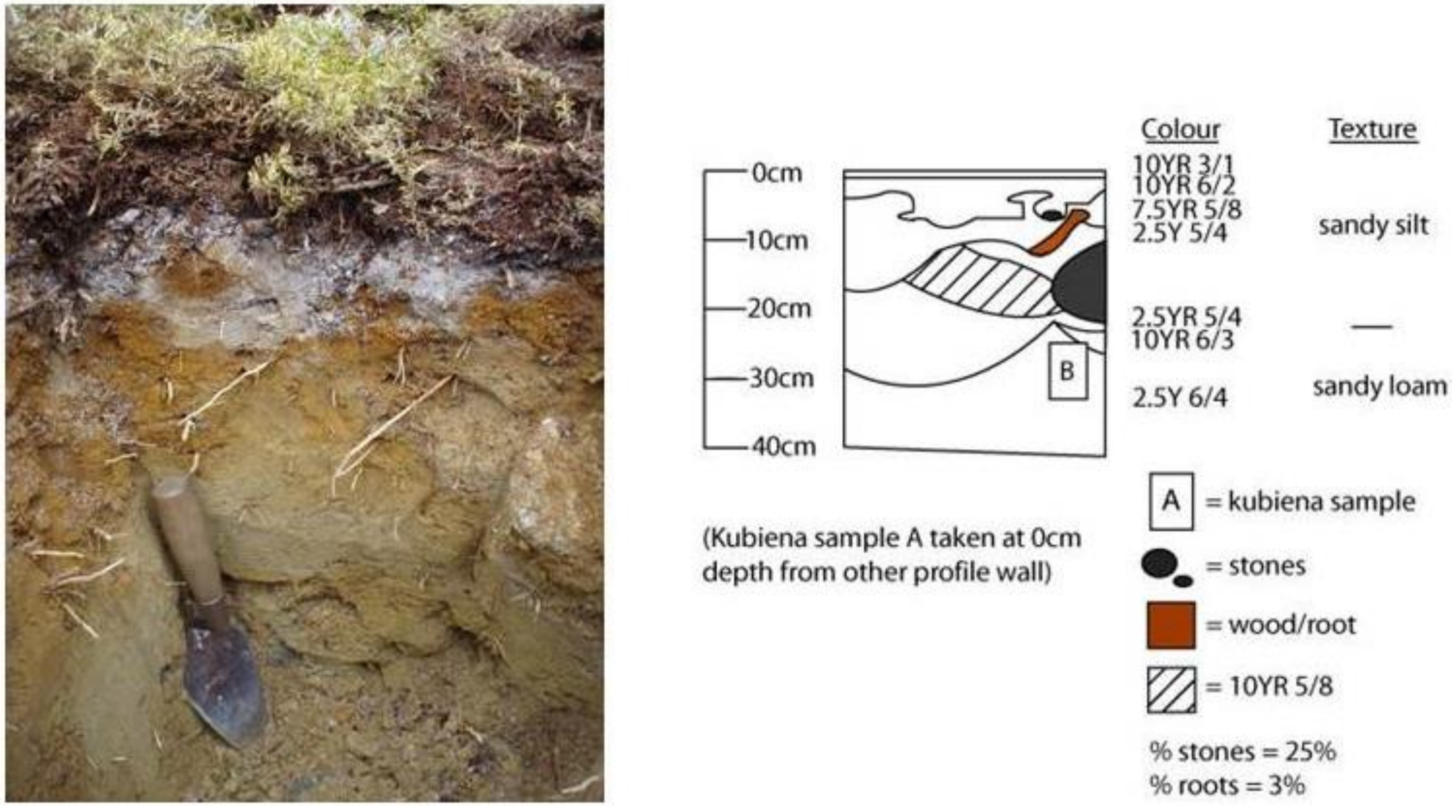


Figure 5.41: Photograph and soil profile diagram of profile 3

5.3.4.4 Profile 4

5.3.4.4.1 Description

Slide 4B was taken at a depth of 2cm from the profile face adjacent to where slide 4A was taken; see figure 5.44 for soil profile drawing and location of slide and table 5.4 for the micromorphology description tables. The B-horizon is iron and organic rich (20% and 39% respectively) with an overall weak crumb microstructure which is starting to develop lenticular voids. The mineral grains have very few size 1 silt capping's and size 2 organic carbon coatings.

The overlying E-horizon has been mixed and contains traces of the underlying B-horizon and the past A-horizon; size 1 silt capping's are rare. The large pieces of charcoal occur in a linear pattern. Size 2 organic carbon coatings are common throughout which is an increase in both frequency and size from the underlying B-horizon (very few size 1).

The overlying anthropogenic micro-stratum is derived from a mixture of added mineral and organic material, namely E and B horizon material, in addition to a mixture of charcoal and turf material; see figures 5.42 and 5.43 for photographs of turf material and partially charred organic material. Silt capping's up to size band 3 are rare. Very few of the mineral grains have size 2 organic carbon coatings which is less, frequency wise, than in the lower charred/E horizon.

Slide 4A was taken at a depth of 0cm and incorporates the anthropogenic topsoil as seen in slide 4B (although from another face of the profile).

The anthropogenic topsoil material is very similar to that seen in slide 4B as it has been taken from the same profile however as this slide has been taken 2cm higher than slide 4B, and from another face within the profile, the full depth of the stratum can be analysed. The composition of the anthropogenic material is very similar in both slides but is more homogenised in slide 4A with a lower concentration of charcoal. Silt cappings (size 2) are rarely seen on the mineral grains which are up to size band 4 with organic carbon coatings up to size 1 occurring rarely. The iron level reduces towards the top of the stratum which graduates into a newly forming E-horizon.

The E-horizon is indicated by the reduced iron levels, change in colour from brown to grey and compacted nature of the fine mineral material in comparison to the anthropogenic topsoil. The newly formed E-horizon is overlain by an organic accumulation which has a very limited and small grained mineral content (2% quartz, size 1). The organic A-horizon has been very biologically active (5% spheroidal excremental material) and is highly decomposed and almost completely homogenised; see figures 5.45 and 5.46 for photographs of the organic accumulation overlying the forming E-horizon.

5.3.4.4.2 Interpretation

Slide 4B incorporates the upper B and E horizon plus a charred micro-stratum and the lower anthropogenic topsoil. The B-horizon is iron and organic rich as expected with the illuviation deposits. The establishment of lenticular voids over the weak crumb microstructure is indicative of a very cold environment; as lenticular structures are typically found within the E-horizon, not in the lower B-horizon. The size 1 silt capping's indicate the age of the stratum with the size 2 organic coatings being linked to the illuviation process; the carbon percolates down profile along with the other illuviating materials.

The E-horizon is disturbed and partially destroyed from being mixed with the underlying B-horizon and overlying A-horizon. The large charcoal fragments positioned in a linear pattern indicate that a moderate charring episode occurred, possibly surface vegetation from the size of the charcoal fragments. As there is evidence of light mixing/disturbance to the the stratum the charring may also have been the result of a clearance episode; the organic coatings can be linked to the higher availability of carbon from the charred organic material.

The overlying anthropogenic stratum shows evidence of the mixing seen in the E-horizon through the inclusion of pockets of E and B-horizon material. The inclusion of size 3 silt capping's here is further indication of the level of mixing and indicates that, due to the size of the coatings, mineral material from elsewhere in the site has been deposited and mixed into the topsoil. The inclusion of large charcoal and turf fragments indicate that they were added to the soil as part of the amendment process in order to fertilise the soil. The very few size 2 organic coatings, less than in the lower charred and underlying E-horizon, further supports the link between increased availability of carbon and increased frequency and size of organic carbon coatings. As there has been a great deal of disturbance within this stratum, alongside a limited charcoal input, the organic carbon coatings situated within the same stratum as a burning episode occur more frequently. The discreet pockets of E and B-horizon material throughout the anthropogenic topsoil indicate that although there is evidence of mixing, it has not been intensively used as the soil material has not been mixed to the point where the microstructure became homogenised.

Slide 4A was taken from the surface of the anthropogenic topsoil and contains the same material seen in the upper of slide 4B. However it also contains a very weakly developed E-horizon and overlying organic accumulation which has not been seen elsewhere. Although the components of the anthropogenic stratum are almost identical between the two slides, the structure differs in that the material nearer the surface in slide 4A is more homogenised but the amount of charcoal present decreases with decreasing depth. This could either have been the result of illuviation/eluviation process or indicates that the profile was being more intensely used over time but the addition of fertilising materials lessened. Silt capping's are still present indicating that mineral inputs to the soil were continued until abandonment. As it would be extremely unusual to change the land management regime to remove the fertilising input to the soil the smaller percentage of charcoal and reduced organic coatings has been linked to the podsolization processes.

The E-horizon is indicated by the reduced iron levels, change in colour from brown to grey, and the compacted nature of the fine mineral material in the stratum towards the top of the anthropogenic topsoil. The E-horizon formation indicates that the site has been abandoned and that the profile is reverting to its natural state, something which has not been seen in the other profiles. It is overlain by an organic accumulation which is further evidence of the abandonment of the site; the lack of mineral input indicates a stable environment.

Overall, this profile has been a natural podzol which has been prepared for cultivation by the clearance and charring of the surface vegetation and continuing addition of mineral and organic material. The input of mineral material and turf has continued throughout the lifespan of this micro-stratum. Most interestingly however is that after the site has been abandoned an organic accumulation has begun forming over the anthropogenic topsoil with an E-horizon forming directly below it. This process of the profile returning to its natural state by re-podzolising is not visible in the other two abandoned anthropogenic profiles at this site, which could be the result of differing conditions from profile to profile but is evidence of past anthropogenic sites being able to return to their natural state and it occurring relatively quickly after abandonment (Gammelhemmet was abandoned in AD1801 after 100 years of occupation), which fits with the podzol model identified in chapter 2, will be extremely useful for further studies of abandoned European cultural soils in acidic podzol environments.

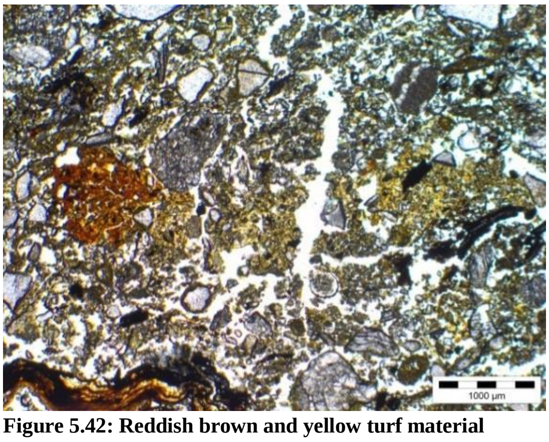


Figure 5.42: Reddish brown and yellow turf material PPL x2 mag

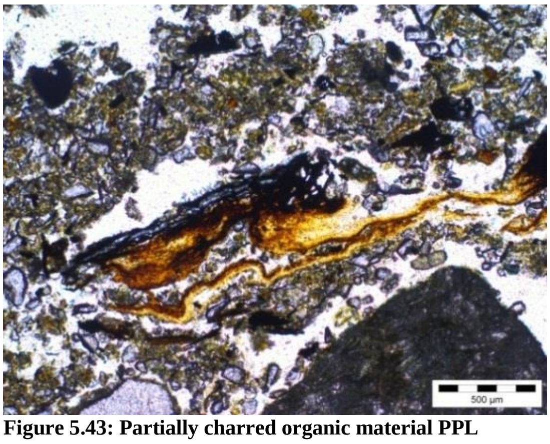


Figure 5.43: Partially charred organic material PPL x4 mag

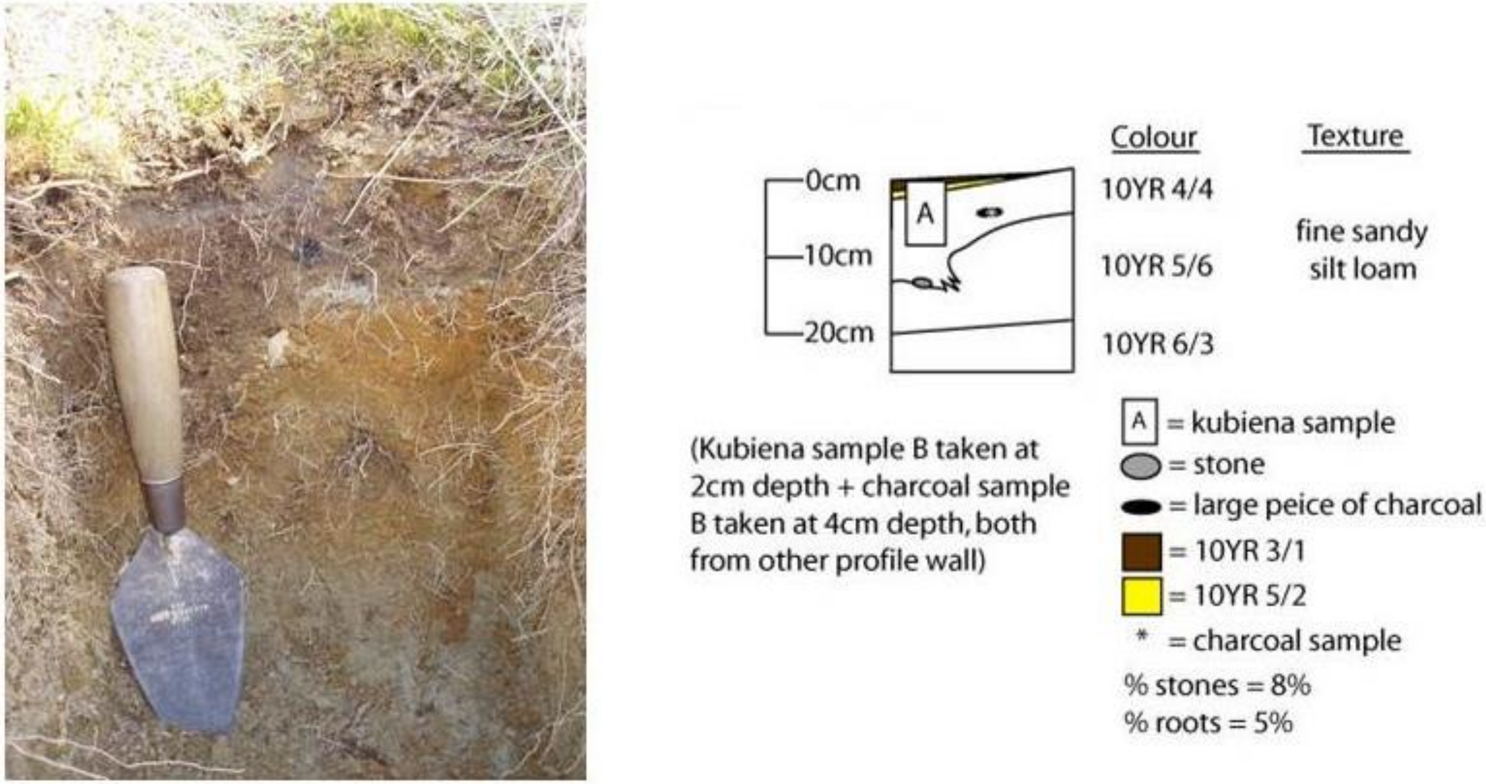


Figure 5.44: Photograph and soil profile diagram of profile4

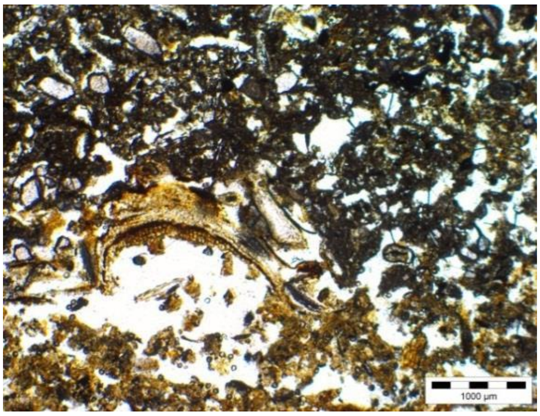


Figure 5.45: Newly developing E horizon overlain by organic accumulation PPL x2 mag

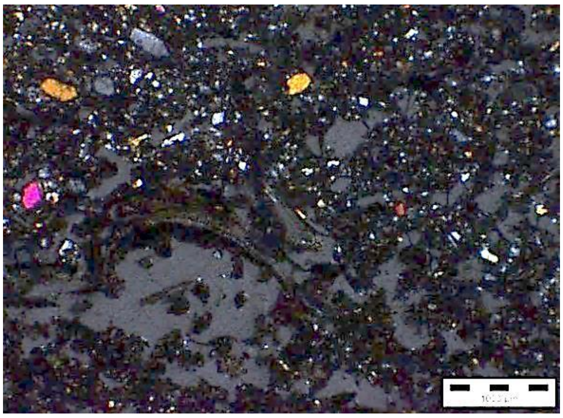


Figure 5.46: Newly developing E horizon overlain by organic accumulation XPL x2 mag

5.3.4.5 Profile 5

5.3.4.5.1 Description

Slide 5A was taken at a depth of 0cm; see figure 5.49 for soil profile drawing and location of slide and table 5.4 for the micromorphology description tables. The B-horizon of the profile is unusual as although a decrease in iron content and discreet micro-strata are anticipated with depth, a discreet band of micro-charcoal is present at the bottom of this slide; see figures 5.47 and 5.48 for photograph of part of this charcoal stratum. This stratum (2% of slide area) occurs in an undulating but continuous linear band and marks a change in iron content from 40% above to 20% in and below; iron content refers to the percentage of iron stained mineral grains. This micro-stratum has very little size 1 silt capping's and rare size 1 organic carbon coatings.

The overlying B-horizon material is more typical of a B-horizon and is rich in iron stained minerals (40%) with a high organic 'root' type content (15% coarse organic material). A trace of charcoal is present in this micro-stratum but is spread out randomly rather than in a linear fashion as seen in the lower micro-stratum. Silt capping's on mineral grains occur less frequently (size 1 capping's are rare) but the organic carbon coatings occur more frequently and in a larger size (very few up to size band 2). The third micro-stratum is the upper B-horizon is marked visibly by the colour change from orangey brown in the lower stratum to reddish brown. The mineral grain size is smaller again with no silt capping's present with the organic coatings increasing in size and frequency (size 3 coatings common).

The E-horizon is iron free and very shallow with a trace of micro-charcoal and a single larger piece of charcoal present in the top left of the slide. Organic carbon coatings are still common but have decreased in size from the lower stratum (band 2 rather than band 3 seen in the lower micro-stratum).

Directly overlying the E-horizon is a band of coarse charred material which is again overlain by a thin organic stratum with minimal mineral material (2% quartz).

5.3.4.5.2 Interpretation

Slide 5A incorporates the B-horizon, E-horizon and overlying charred micro-stratum, with its subsequent organic accumulation. The silt capping's in the B-horizon indicate the age of the profile with the rare carbon coatings demonstrating the on-going podsolization processes. The microstructure and groundmass of the stratum is indicative of E-horizon type material but with the organic and iron inclusions of a weakly formed B-horizon, and fits with the discreet E and B type horizons seen deep in profile 3.

The overlying B-horizon fits with the typical iron and organic rich model seen at the other sites and profiles. The occurrence of silt capping's decreases, which is to expected with decreasing depth. However the organic carbon coatings occur more frequently, and in a larger size. This indicates an increased availability of carbon even though there is a reduced percentage of visible charcoal, which in turn indicates that the micro-charcoal band seen in the lower stratum has been percolated down the profile and deposited at the bottom of the B-horizon proper; which ties in neatly with the undulating nature of the deposit fitting exactly along the undulating boundary between the two micro-stratum. The colour change between the second and third strata can be explained by the increase in iron staining of the mineral grains to 60%; 40% in the lower stratum. The further increase in organic coatings suggests a closer proximity to the charcoal source.

The E-horizon is very shallow which may be the reason for the lack of a lenticular microstructure. The decrease in the organic carbon coating size indicates that the carbon source is near but also that larger pieces of charcoal can, and have, moved down profile.

The overlying charred stratum is very coarse in size, which although now partially fragmented appears to have originated from a singular piece of wood; designated as wood due to the size of the fragments. A single continuous charcoal layer like this has not been seen in the previous profiles/sites and indicates that the material has been burnt *in situ* but is not the surface vegetation and points towards, if anthropogenic, slash and burn style clearance of the site or if natural, a more intensive forest fire. The low mineral content of the overlying organic accumulation indicates that there has been little to no disturbance on/above this profile, and that the organic accumulation has not been stripped for burning material or addition to the cultivated soils. Clearance and charring of vegetation has been part of the preparation of podzol soils for cultivation in some of the anthropogenic profiles it is possible that this area was being prepared for cultivation just prior to abandonment and the intact nature of the charcoal stratum and overlying organic accumulation is due to the abandonment of the site rather than it never being intended for cultivation. However, as naturally induced forest fires are common in the area and are clearly visible in the undisturbed Sámi profiles and with evidence of the charred strata being mixed into the anthropogenic topsoil's as in profile 4 as well as the historic nature of the charcoal in question this burning episode has been deemed as natural; deemed historic due to the depth of the migrating micro-charcoal.

Overall this profile shows a natural, physically undisturbed podzol with a very high iron accumulation in the uppermost part of the B-horizon suggesting the possible formation of an iron pan. However the pore space of this stratum is 25% which would have allowed for the percolation of the micro-charcoal from the upper charred material down throughout the profile to where it has currently accumulated. This accumulation fits with the undulating nature of the underlying stratum and marks the boundary between it and the upper stratum. As a few larger (up to size 3) charcoal pieces have migrated down profile to the B-horizon then the movement and re-deposition of the micro-charcoal several strata down profile is more than plausible and opens up the possibility that this movement of micro-charcoal significantly down profile may have occurred at the previous profiles and/or sites but that either the kubiena samples were not obtained deep enough to capture the re-deposition or, depending upon when the charring event occurred, the micro-charcoal band may have already migrated beyond the studied strata.

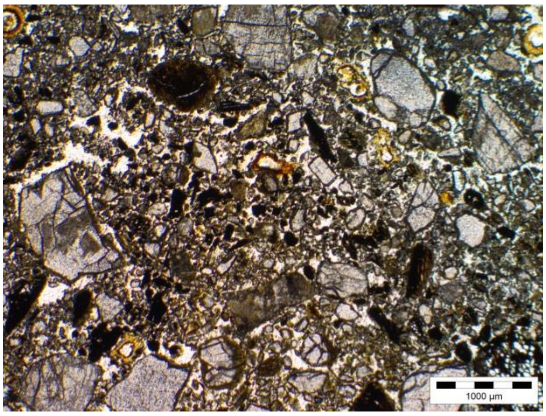


Figure 5.47: Micro-charcoal band marks boundary between micro-strata 4 and 5 PPL x2 mag

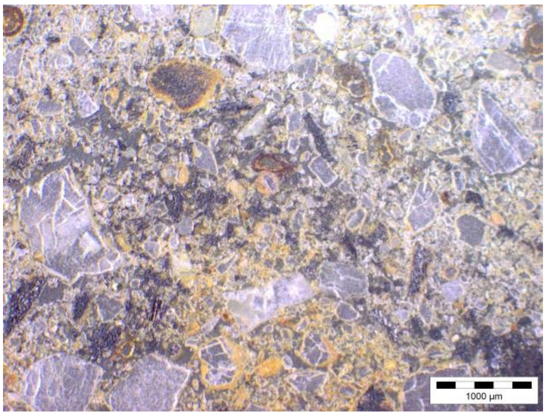


Figure 5.48: Micro-charcoal band marks boundary between micro-strata 4 and 5 OIL x2 mag

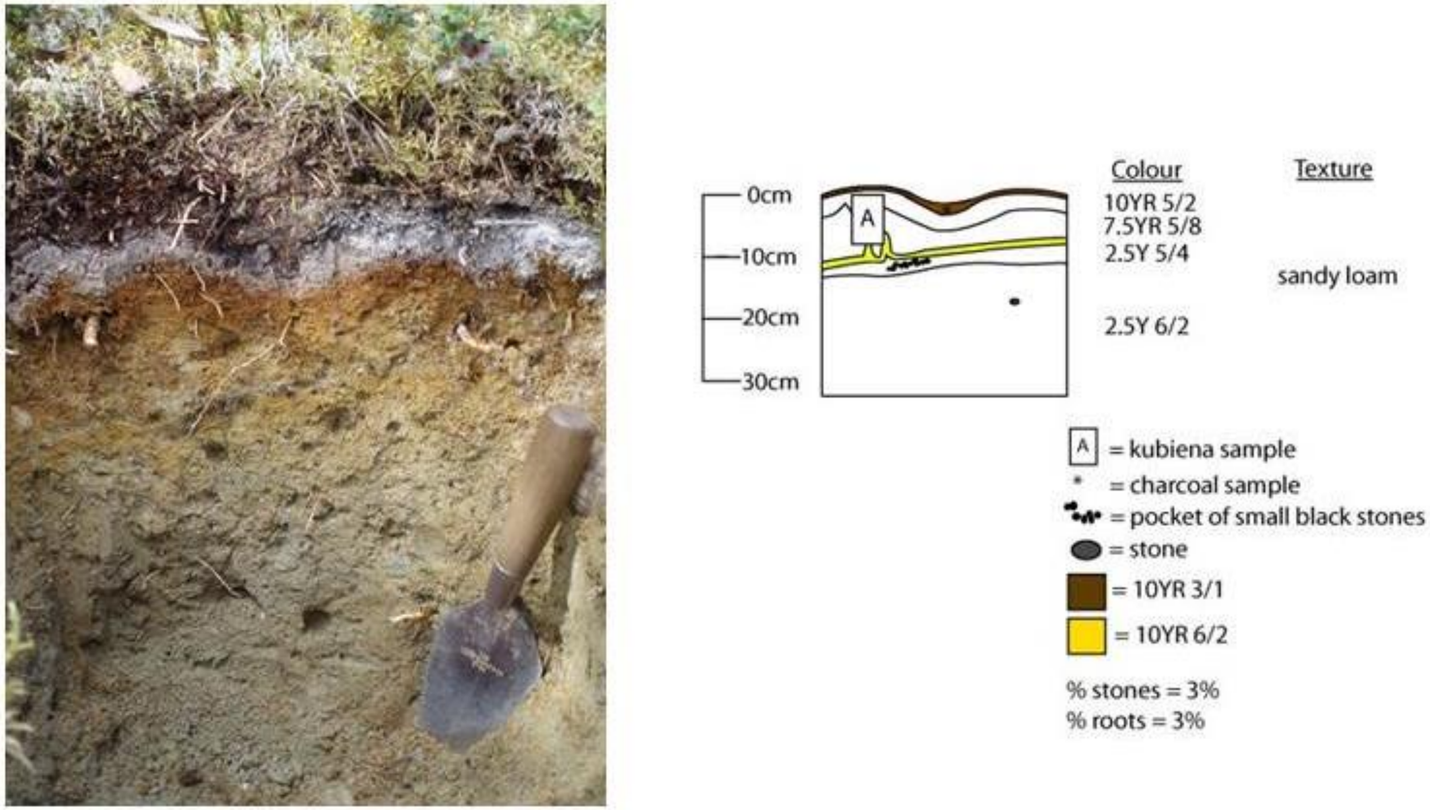


Figure 5.49: Photograph and soil profile diagram of profile 5

5.3.4.6 Summary

This site has a mixture of anthropogenically developed and cultivated topsoils and natural podzols. This is the only site studied which has been abandoned and the abandonment, and in once case re-podzolisation, is well documented within the soil. Overall, the cultivated soils have been formed from similar preparation techniques to Hornmyr whereby large vegetation is removed, and in the case of profile 4 the surface vegetation is charred, before mineral material from elsewhere was added alongside turf material before being mixed and cultivated. The addition of these materials, as well as charcoal, continued throughout the lifespan of the cultivated soils. Profile 4 is of particular interest and showed the same preparation and inputs as the other cultivated profiles but showed a decrease in charcoal with decreasing depth. This has been linked to a reduced interest in the profile in preparation of abandonment however as this profile has begun re-podzolise, with an E-horizon developing at the top of the past anthropogenic topsoil and both micro and size 3 charcoal pieces having moved considerably down profile in profile 5, it is possible that the reduction in charcoal with proximity to the surface is a result of the charcoal migrating down profile rather than a diminishing cultural interest in the profile.

The natural redevelopment of an E-horizon at the top of the past anthropogenic topsoil in profile 4 indicates that all anthropogenically modified soils may return to their natural state post abandonment. As Gammelhemmet was abandoned in AD1801 and as podzol soils are argued to take between 100 to 4,780 years to form (Juahiainen 1972 and WRB 2006 respectively), it indicates that this return to the natural state came into effect almost immediately after abandonment which fits with the podzol model formed in chapter 2. This indicates that if anthropogenic topsoil's were to be miss-managed in this area that they may begin re-podzolising whether abandoned or not.

Table 5.4: Micromorphology description tables for Gammelhemmet slides

				Coarse mineral material (>10µm)														Coarse Organic material (>10µm)								Fine Organic Material (<10µm)				Pedofeatures				Structure			
Profile	Micro-strata	Depth (cm)	Quartz %	Quartz maximum size	Feldspar %	Feldspar maximum size	Siltstone %	Siltstone maximum size	Mica %	Mica maximum size	Glauconite %	Arrangement of minerals	Fine mineral material (<60µm)	Silt coating frequency	Silt coating maximum size	Organic carbon coatings frequency	Organic carbon coating maximum	Organ residue	Tissue residue	Largest tissue residue (mm)	Lignified tissue	Sclerotia	% Charcoal	Largest charcoal	Cell residue	Amorphous black	Amorphous yellow	Amorphous brown	Amorphous red	Excremental (*Spheroidal*) 50-100µm	Fe impregnated mineral material %	Fe impregnated organic material %	% void space	Microstructure	Course material arrangement	Groundmass b fabric	C/F ratio
1A	1		20	2	5	2	2	1	2	1	-	R	Grey + low IC	1	1	1	2	-	-	-	t	1	-	-	10	5	t	t	t	25	5	15	30	Weak pedality, crumb	Partially sorted, un-accommodated	Single spaced fine enaulic. Orangey grey SS	2/1
	2		20	4	15	4	10	3	2	1	-	R	Grey + low IC	-	-	3	3	5	5	500 x 200	5	1	10	4	5	5	t	t	-	-	5	15	20	Weak pedality, granular	Unsorted, and well accommodated	Close fine enaulic, grey SS	3/1
	3		20	4	10	3	10	2	2	1	t	R	Grey + low IC	2	2	1	2	t	5	100 x 25	t	-	2	1	10	5	10	t	t	-	5	20	20	Weak pedality, granular	Unsorted, and well accommodated	Close fine enaulic, grey SS	3/1
	4		45	3	-	-	-	-	-	-	-	SR	Grey + low IC	2	3	-	-	-	-	-	-	-	t	1	-	t	t	50	t	-	20	60	5	Massive. No pedality	Partially sorted, well accommodated	Close porhyric, brown SS	1/1
1B	1		20	3	5	3	5	1	2	1	-	SR	Grey + low IC	-	-	-	-	t	5	50 x 50	15	-	10	2	5	10	5	t	t	-	t	t	20	Weak pedality, lenticular	Unsorted, well accommodated	Close fine enaulic, grey SS	2/1
	2		25	3	10	4	5	1	t	1	-	SR	Grey + low IC	1	3	1	2	-	-	-	15	-	t	2	10	10	5	t	t	-	t	-	15	Weak pedality, lenticular	Unsorted, well accommodated	Close fine enaulic, grey SS	3/1
	3		25	3	10	2	5	5	t	1	-	SR	Grey + low IC	1	3	-	-	5	5	100 x 50	t	-	-	-	5	10	5	t	-	-	25	t	30	Weak pedality, crumb	Partially sorted & accommodated	Close fine enaulic yellow/grey SS	2/1

				Coarse mineral material (>10µm)														Coarse Organic material (>10µm)								Fine Organic Material (<10µm)				Pedofeatures				Structure			
Profile	Micro-strata	Depth (cm)	Quartz %	Quartz maximum size	Feldspar %	Feldspar maximum size	Siltstone %	Siltstone maximum size	Mica %	Mica maximum size	Glauconite %	Arrangement of minerals	Fine mineral material (<60µm)	Silt coating frequency	Silt coating maximum size	Organic carbon coatings frequency	Organic carbon coating maximum	Organ residue	Tissue residue	Largest tissue residue (mm)	Lignified tissue	Sclerotia	% Charcoal	Largest charcoal	Cell residue	Amorphous black	Amorphous yellow	Amorphous brown	Amorphous red	Excremental (*Spheroidal*) 50-100µm	Fe impregnated mineral material %	Fe impregnated organic material %	% void space	Microstructure	Course material arrangement	Groundmass b fabric	C/F ratio
1C	C		40	5	20	5	10	5	5	1	t	R	Grey + low IC	5	5	-	-	t	-	-	-	-	-	-	5	5	t	-	t	-	t	t	20	Weak pedality, granular	Unsorted & partially accommodated	Close fine enaulic, grey SS	5/1
2A	1		20	4	10	2	5	3	2	2	-	SR	Grey + low IC	5	5	2	5	5	5	100 x 50	10	-	2	3	10	10	5	-	t	t	10	5	20	Weak pedality, granular	Unsorted & partially accommodated	Close fine enaulic, grey/yellow SS	4/1
	2		20	3	20	4	20	3	2	1	t	SR	Grey + low IC	4	3	2	3	2	2	100 x 50	2	-	-	-	5	5	5	5	t	t	10	t	10	Moderate pedality, crumb	Unsorted & partially accommodated	Close fine enaulic, grey/yellow SS	3/1
3A	1		20	3	10	2	10	1	2	1	-	SR	Grey + low IC	-	-	2	3	2	2	50 x 50	5	5	t	1	2	10	5	t	t	t	t	t	30	Well developed, lenticular	Well sorted, partially accommodated	Close fine enaulic, grey SS	2/1
	2		20	2	10	2	5	2	t	1	t	SR	Grey + low IC	1	5	1	3	15	5	50 x 50	t	-	-	-	5	t	5	10	t	t	30	30	20	Weak pedality, granular	Unsorted, partially accommodated	Close fine enaulic, orange grey SS	2/1
3B	1		35	2	20	1	20	2	10	1	-	SR	Grey + low IC	1	3	2	3	2	-	-	-	-	-	-	t	t	-	t	t	-	20	15	10	Weak pedality, lenticular	Unsorted & well accommodated	Single spaced porphyric, grey SS	1/3
	2		30	4	20	5	10	5	2	2	-	SR	Grey + low IC	1	5	-	-	5	5	150 x 50	-	-	-	-	5	5	t	t	2	-	40	-	15	Well developed, lenticular	Unsorted & well accommodated	Single spaced fine enaulic, grey SS	1/3

			Coarse mineral material (>10µm)														Coarse Organic material (>10µm)								Fine Organic Material (<10µm)				Pedofeatures				Structure			
Profile	Micro-strata	Depth (cm)	Quartz %	Quartz maximum size	Feldspar %	Feldspar maximum size	Siltstone %	Siltstone maximum size	Mica %	Mica maximum size	Glauconite %	Arrangement of minerals	Fine mineral material (<60µm)	Silt coating frequency	Silt coating maximum size	Organic carbon coatings frequency	Organic carbon coating maximum	Organ residue	Tissue residue	Largest tissue residue (mm)	Lignified tissue	Sclerotia	% Charcoal	Largest charcoal	Cell residue	Amorphous black	Amorphous yellow	Amorphous brown	Amorphous red	Excremental (*Spheroidal*) 50-100µm	Fe impregnated mineral material %	Fe impregnated organic material %	% void space	Microstructure	Course material arrangement	Groundmass b fabric	C/F ratio
4A	1		2	1	-	-	-	-	-	-	-	SR	Grey + low IC	-	-	1	1	30	5	100 x 50	t	1	-	-	5	t	t	30	t	5	-	-	25	Weak pedality, crumb	Unsorted, partially accommodated	Double spaced porphyric, brown SS	1/3
	2		20	1	10	2	5	1	2	1	-	SR	Grey + low IC	-	-	1	3	-	2	100 x 50	t	-	-	-	10	10	10	10	-	-	t	t	20	Weak pedality, crumb	Well sorted & partially accommodated	Double spaced porphyric, brown SS	1/1
	3		20	4	10	2	10	1	2	1	t	SR	Grey + low IC	2	2	1	2	2	-	-	10	-	5	3	5	10	t	-	t	2	20	5	25	Weak pedality, crumb	Unsorted & partially accommodated	Close fine enaulic, brown SS	2/1
4B	1		20	4	20	3	10	1	t	1	-	SR	Grey + low IC	3	2	2	3	t	-	-	10	-	5	6	5	10	2	t	2	t	20	5	20	Weak pedality, crumb	Unsorted & partially accommodated	Close fine enaulic, brown SS	2/1
	2		20	5	10	1	5	2	t	1	-	SR	Grey + low IC	1	2	2	5	-	-	-	30	-	t	5	t	10	2	2	-	-	t	-	20	Moderate pedality, lenticular	Unsorted & accommodated	Close fine enaulic, grey SS	2/1
	3		20	3	5	2	5	1	t	1	t	SR	Grey + low IC	1	3	2	3	-	5	250 x 25	-	-	-	-	10	2	10	10	2	-	20	-	20	Weak pedality, crumb	Partially sorted & accommodated	Single spaced fine enaulic, grey brown SS	3/1
5A	1		2	1	-	-	-	-	-	-	-	SR	Grey + low IC	-	-	2	5	5	5	100 x 100	2	-	40	6	10	-	5	2	-	-	-	10	30	Weak pedality, granular	Well sorted, partially accommodated	Close fine enaulic, orange SS	4/1

				Coarse mineral material (>10µm)														Coarse Organic material (>10µm)								Fine Organic Material (<10µm)				Pedofeatures				Structure			
Profile	Micro-strata	Depth (cm)	Quartz %	Quartz maximum size	Feldspar %	Feldspar maximum size	Siltstone %	Siltstone maximum size	Mica %	Mica maximum size	Glauconite %	Arrangement of minerals	Fine mineral material (<60µm)	Silt coating frequency	Silt coating maximum size	Organic carbon coatings frequency	Organic carbon coating maximum	Organ residue	Tissue residue	Largest tissue residue (mm)	Lignified tissue	Sclerotia	% Charcoal	Largest charcoal	Cell residue	Amorphous black	Amorphous yellow	Amorphous brown	Amorphous red	Excremental (*Spheroidal*) 50-100µm	Fe impregnated mineral material %	Fe impregnated organic material %	% void space	Microstructure	Course material arrangement	Groundmass b fabric	C/F ratio
	2		40	2	20	2	10	1	t	1	-	SR	Grey + low IC	-	-	2	5	5	t	50 x 25	2	-	t	3	t	2	2	t	t	-	-	t	20	Weak pedality, crumb	Partially sorted & accommodated	Close fine enaulic, grey SS	4/1
	3		20	3	10	2	5	1	t	1	-	SR	Grey + low IC	-	-	3	5	t	5	150 x 50	-	-	t	1	20	t	5	5	t	5	60	20	25	Weak pedality, crumb	Unsorted, partially accommodated	Close fine enaulic reddish brown SS	3/1
	4		20	3	10	4	2	1	t	1	5	SR	Grey + low IC	1	2	2	3	5	10	100 x 50	-	-	t	2	10	t	10	5	t	-	40	20	20	Weak pedality, granular	Well sorted, partially accommodated	Close fine enaulic, grey yellow SS	2/1
	5		20	2	10	2	5	1	t	1	t	SR	Grey + low IC	1	3	1	2	2	10	250 x 50	15	-	2	3	5	5	5	t	t	2	20	5	20	Weak pedality, granular	Well sorted, partially accommodated	Close fine enaulic, grey yellow SS	2/1

5.3.5 Chemical analysis

5.3.5.1 pH

As with the pH values at Kåddis, the values here also do not fit with the emerging decrease in acidity with depth seen in the podzolic soils; profiles 3 and 5 are the control samples. From looking at the acidity levels it would appear that profiles 1 and 2 have been more intensively managed as they are the least acidic with profile 4, identified as the original home-field, having a more acidic topsoil (see figure 5.50). A secondary albic horizon within the topsoil has been identified through the field and micromorphological analysis which is supported by the low pH value seen.

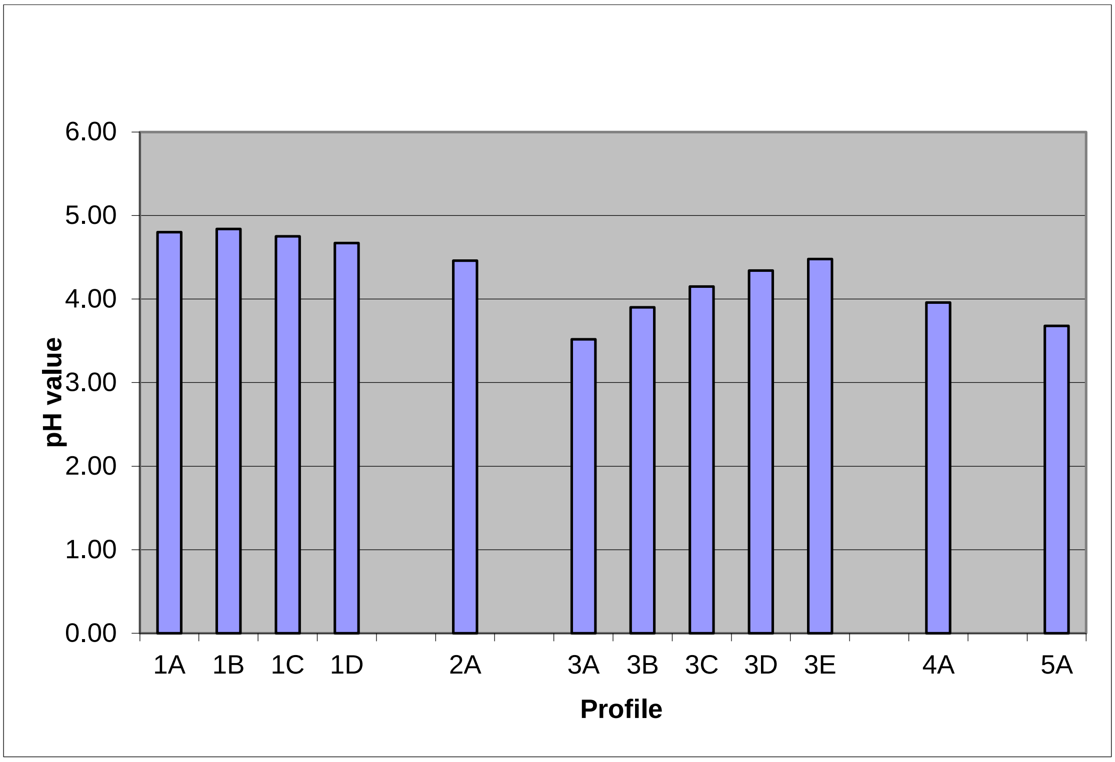


Figure 5.50: Bar graph showing pH values for all profiles at Gammelhemmet

5.3.5.2 Magnetic susceptibility

The magnetic susceptibility values for the Gammelhemmet site show that profiles 1 and 2, both anthropogenically amended profiles, have higher magnetic values than the control samples (profile 3); see figure 5.51. As the control samples have a much lower magnetic value it can be assumed that the increase seen in the anthropogenically altered soils is a result of anthropogenic activity and/or amendment. This indicates that profiles 1 and 2 have been subjected to either more burning events or had charred organic material applied to them as part of the European land management regime.

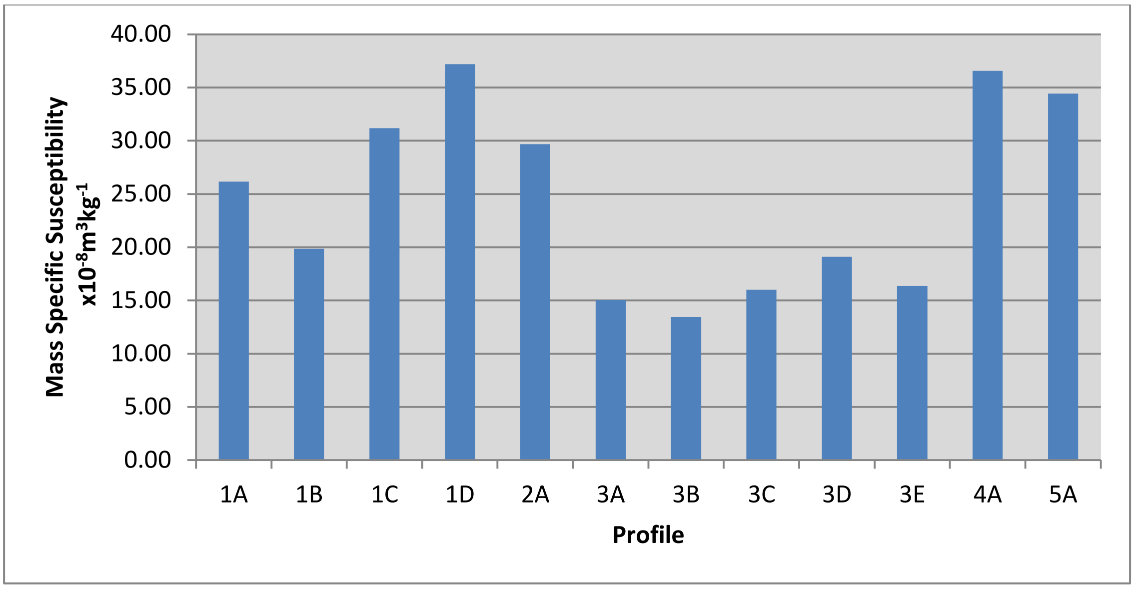


Figure 5.51: Mass Specific Magnetic Susceptibility values for Gammelhemmet

5.3.5.3 SEM analysis

One way ANOVA's were carried out comparing each soil horizon from each of the three sites. The phosphorous levels in the anthropogenic topsoil's at the three sites were statistically distinct from one another (see figure 5.52). As the base soil at each site is podzolic this spread in values is most likely linked to the land management techniques employed at each site i.e. the applied materials.

```
Source   DF      SS      MS      F      P
Site      6  1.2490  0.2082  11.85  0.000
Error    20  0.3515  0.0176
Total    26  1.6005

S = 0.1326   R-Sq = 78.04%   R-Sq(adj) = 71.45%

                           Individual 95% CIs For Mean Based on
                           Pooled StDev
Level        N    Mean   StDev  ---------+---------+---------+---------+
Hornmyr      9  0.0578  0.0335          (--*--)
Gammelhemmet 6  0.3400  0.2425                   (--*---)
Kåddis       3  0.6700  0.1500                            (----*-----)
                                ---------+---------+---------+---------+
                                      0.00      0.30      0.60      0.90
```

Figure 5.52: Output from Tukey's multiple comparisons regarding the Phosphorous levels in the topsoil at Hornmyr, Gammelhemmet and Kåddis

5.3.6 Summary

The same high degree of amorphous material and homogeneity in the microstructure as well as the added materials seen at the Kåddis site is seen here. The micromorphological analysis has however also revealed a high input of mineral material to the amended topsoils which was not seen at Kåddis. This input of mineral material is evidenced through the increased depth in the field analysis and the inclusion of thick periglacial silt cappings associated with the lower E and B horizons within the topsoil. As these cappings were rare at the Kåddis site due to it overlying sand deposits but the topsoil was significantly deeper than in the control samples it is almost certain that mineral material was added, it's simply that there is no evidence linking the inputted material to its original location as seen here.

As Gammelhemmet has been abandoned it provides an interesting case study to what can happen to the amended soils post occupation. Most interestingly a secondary albic horizon has begun to develop within the anthropogenic topsoil at profile 4, identified through the field and micromorphological analysis and supported by the low pH value. This is strong evidence of the on-going podsolization processes in amended podzols and demonstrates their fragility. The formation, or reformation, of a podzol as a consequence of abandonment of a cultural soil was identified in the podzol model formed in chapter 2.

The cultural indicators identified at the site fit with those established at Kåddis but are supplemented by the inclusion of displaced silt capped mineral grains within the anthropogenic topsoil. As the silt cappings were only present within the lower soil horizons in the undisturbed control samples but were common within the anthropogenic topsoil, the occurrence of displaced mineral material can be used as an indicator of European 'plaggen' style cultivation.

5.4 Hornmyr

5.4.1 Background

Hornmyr is situated on basic intrusive and volcanic bedrock and podzol soil (Swedish Geological Society, 2010). It was settled in AD1764, whilst the Gammelhemmet site was still occupied, by Olof Andersson and his wife (Lindholm 2008). Olaf was originally from Innervik, Skellefteå, but moved to Örträsk and married Sophia Samuelsdotter before settling a farm in Hornmyr in order to evade conscription (Andersson, B. *pers. comm;* Genealogy record, 2011). It is believed that the couple received an extension on the usual 15 year tax exemption period due to the extremely stony nature of the soil (Andersson, B. *pers. comm*).

The contemporary farm grounds consist of a few meadows surrounding the farmhouse, with birch and pine woodland growing on the outskirts of the meadows; see figure 5.53 for photograph of open meadow. There was also several large (70cm in depth) clearance cairns, which appeared to be historic due to them being almost completely overgrown with moss and other vegetation (see figure 5.54 for photograph of the one which was removed in order to obtain samples; profile 4). The locations of the soil profiles have been mapped in figure 5.55 with the accompanying satellite image in figure 5.56.


Figure 5.53: Photograph of the open meadows at Hornmyr


Figure 5.54: Photograph showing the large clearance cairn overlying profile 4

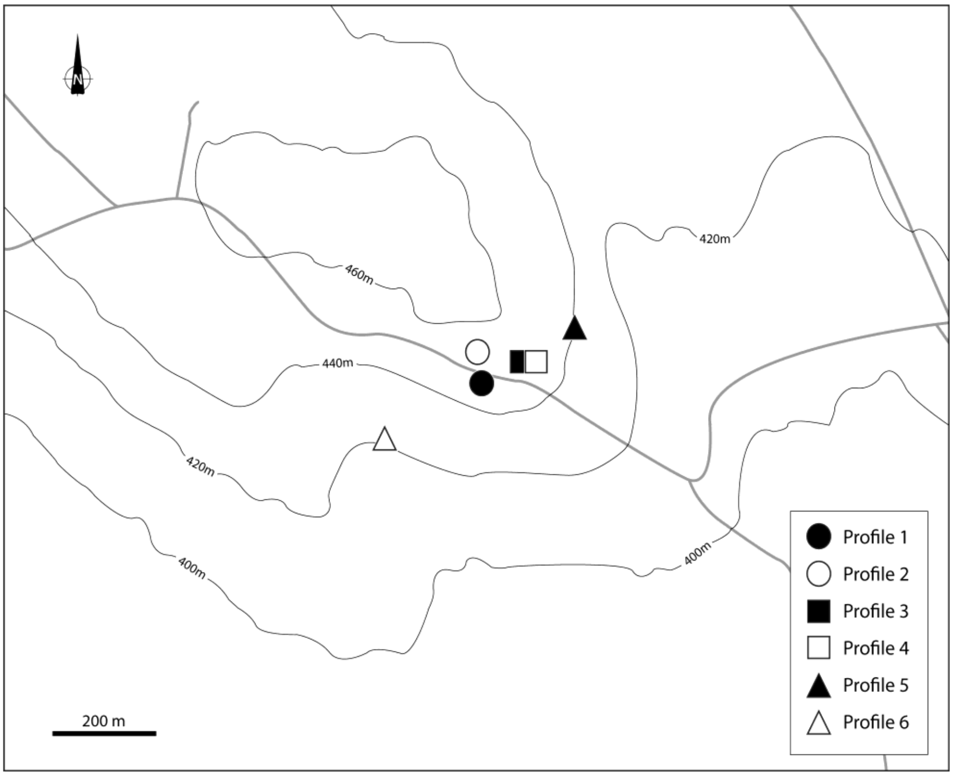


Figure 5.55: Map showing location of all profiles within the Hornmyr site

Figure 5.56: Screen grab of the Google satellite image showing profile locations (Google Maps, 2013)

5.4.2 Study locations

Profile one was situated in a meadow in front of the farmhouse, which was identified by the current owner as the original home-field (Lindberg, T. *pers. comm*). The meadow has a very diverse variety of meadow flowers growing upon it indicating that the soil has not been heavily fertilised. The profile revealed a deep anthrosol, fitting the FAO's plaggen horizon diagnostic criteria of texture, colour, thickness and inclusion of artefacts, overlying a distorted podzol with well-developed albic and spodic horizons. The podzol contains areas where the E and B horizons have been mixed together, which is most likely to have been the result of the original turf being turned when the farm was first settled; see figures 5.57 and 5.58 for photographs showing this mixing. There is also a thin dark horizon below the E-horizon, which could potentially be a past land surface. This will need to be investigated further as if it is an old land surface it could indicate earlier cultivation however it is also possible that as the dark horizon is immediately below, and fades into, the E-horizon, that like the podzols studied in Northern Norway by Elliott (1996) the soils has been inverted through solifluction processes such as freeze/thaw. There is a stone layer present below this turned layer, which will not have affected crop growth or it would have been removed and added to the stone clearance cairns, which are present around the original meadows.

Figure 5.57: Photograph of profile 1 at Hornmyr

Figure 5.58: Annotated photograph of profile 1 at Hornmyr showing evidence of physical mixing i.e. turf turning

Profile two is located in a meadow adjacent to the farmhouse and revealed another deep anthrosol fitting the plaggen criteria, although shallower than profile 1, but with no clear podzol underneath; traces of albic and spodic horizons present but highly mixed. The soil underlying the anthrosol contains mixed layers of greyish and orange material, which may have been the albic horizon (E-horizon) and the underlying sand layer from the original podzol which may have been caused by ploughing of the soil where the podzol has become completely mixed up and has started to homogenize.

Profile three was situated in the same meadow as profile two, but near the edge towards the back of the farmhouse and surrounding pine hinterland. It contained an anthric (moderately thick, dark coloured surface horizon) topsoil but was shallower than the two previous profiles. There is a podzol underlying the topsoil with well defined, but undulating, anthric and spodic horizons that are incomplete in the surrounding profile faces, indicating that the turf has been turned. A similar dark micro-stratum to that in profile 1 is present and is located underneath the albic horizon until halfway across the profile where it goes through the middle; this may be an indicator of solifluction processes as once the soil has been inverted the illuviation/illuviation processes can resume meaning that another E-horizon will begin to develop underneath the overturned soil (Elliott, 1996).

Profile four was situated in the middle of a very large (in both width and depth) clearance cairn after all of the stones had been removed. The profile was very shallow but showed a clearly formed podzol with well-defined albic and spodic horizons with the albic horizon being overlain by a thin layer of brown sand, which may have been present before the clearance stones were added but also may have formed through sand/dust permeating down through the stones as either dust or in water. This podzol can be used as a control for the previous profiles as there are no cultural sediments.

Profile five was located in the forest surrounding the back of profile four and was in an area of mainly birch trees. The profile was extremely waterlogged and consisted of a deep histosol, admixed with laminations of sand, overlying a gleysol showing evidence of the reduction process, and segregation of iron compounds as outlined by the FAO (2006).

Profile six was located in the pine forest surrounding the back of profile one. The profile was again a waterlogged histosol, but was overlying an unconsolidated mineral base rather than a fully developed gleysol.

5.4.3 Chronology

Profile 1 at Hornmyr is believed to be the original home-field from when the site was first settled in AD1764. *In situ* charcoal samples were collected during the fieldwork and were predominantly found within the dark brown, possible past land surface at the bottom of the E-horizon, as well as being distributed randomly throughout the anthropogenic topsoil. Samples were also carefully removed from the bulk soil samples collected. Two samples from the possible second land surface were selected for dating: sample A was collected *in situ* and has been calibrated to AD227-389, and sample D was taken from the bulk soil sample, and has been dated to AD393-539; see table 5.5 for full sample information and figure 5.59 for radiocarbon plot; the sample location is marked on the digitised soil profiles in figures 5.68, 5.72 and 5.76. As the higher end of sample A's date and the lower end of sample D's date are very similar (AD389 and AD393), it is probable that the soils were charred during the same event, and that the age difference can be related to the age, type and location of the charred material (heartwood) that has been identified as *Betula* and *Ericales* respectively. However, the dates indicate an early charring event, which pre-dates all records of European settlement within the interior of northern Sweden and as such, indicates either Sámi charring activity or, which is more likely, a naturally induced forest fire event.

Table 5.5: Table containing information on location, type and age of all radiocarbon dated material from Hornmyr

Site reference	Sample reference	Depth of sample (cm)	Lab code	Material	Radiocarbon Age BP	Calibrated Date (≥95.4%)
Hornmyr	Sample 1A	33	26883 (GU20378)	cf Betula	1745±30	AD 227-389
Hornmyr	Sample 1B	23	26885 (GU20380)	Pinus sylvestris	265±30	AD 1516-1953
Hornmyr	Sample 1C	24	38447 (GU26307)	Ericales	1655±30	AD 260-532
Hornmyr	Sample 1D	35	38448 (GU26308)	Ericales	1610±30	AD 393-539
Hornmyr	Sample 3A	21	26884 (GU20379)	cf Picea	325±30	AD 1478-1644
Hornmyr	Sample 4A	1	26886 (GU20381)	cf Betula	185±30	AD 1650-1955

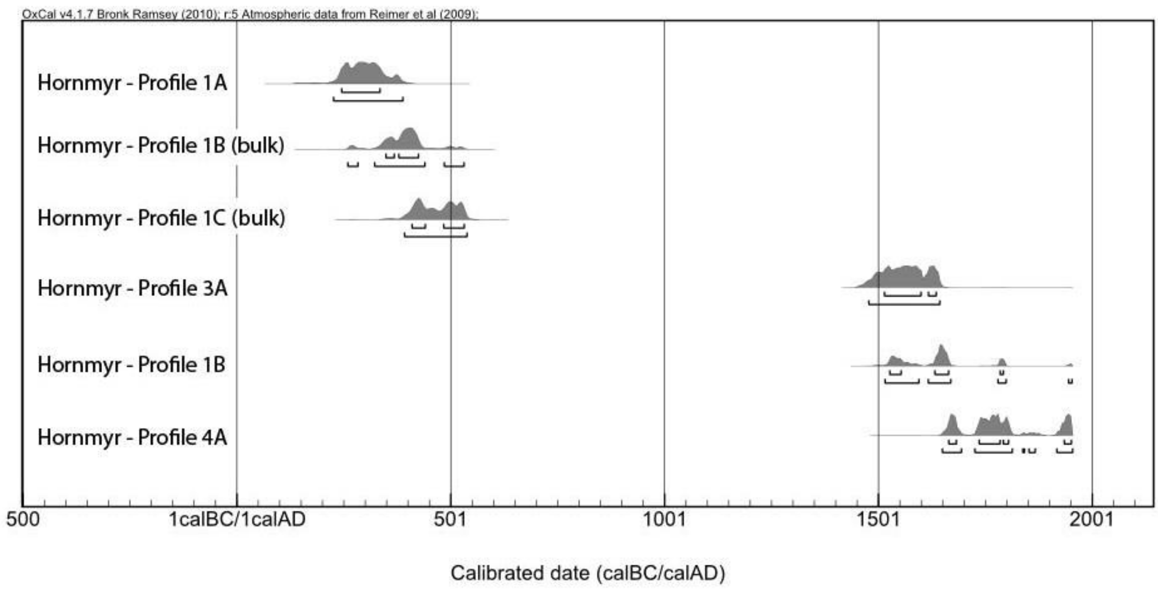


Figure 5.59: Radiocarbon plots showing the calibrated dates for the six samples dated from Hornmyr

Sample B was dated to AD1516-1953 and was taken from the anthropogenic topsoil of the adjoining profile face as there was no visible charcoal within the described profile. Sample C was taken from the bulk soil sample collected at the same depth within the described profile face and was dated to AD260-532, a similar date to samples A and D taken from the possible second land surface (see table 5.5). Sample B fits well with the occupation period and indicates that charred material has been added to the anthropogenic topsoil as a fertiliser, and although sample C is very early in date, this fits with the mixed E and B horizons. This indicates two things, firstly that the original upper horizons have been mixed when the site was settled but also that the podzols natural eluviation and illuviation processes have moved the majority of the charred material down profile and deposited it towards the bottom of the E-horizon.

Profile 3 shows a similar band of charred material to that seen in profile 1, however, the charred band runs through the centre of the E-horizon rather than along the bottom and is much more recent in date having been identified as *Picea* and dated to AD1478-1644; see table 5.5 for full sample information and figure 5.46 for radiocarbon plot. This just pre-dates the occupation period and indicates that there has been a secondary burning event on site and that again the eluviation and illuviation processes have resulted in the fine charred material moving down profile. However as this material is more recent in date there has not been enough time for it to migrate to the bottom of the E-horizon yet. Due to natural differences in vegetation cover and ground morphology it is not uncommon for fires to not blanket burn areas and spread sporadically across the easiest path, which may account for the separate burning events seen at profiles 1 and 4. However, it is also possible that the charred material from both events have percolated down and been deposited in the same micro-stratum resulting in the charcoal samples selected for dating coming from the same horizon but different events.

Profile 4 was located underneath a large stone clearance cairn and was taken as a control sample to demonstrate how the immediate soils of the site were pre-settlement. There was no visible charcoal within the profile faces in the field, however, charcoal was retrieved from the bulk soil sample. This was identified as *Betula* and dated to AD1650-1955, which fits with the period of occupation and further strengthens this profile as a reliable control; the fragment of charred material is aeolian or fluvial in nature and has worked its way through the void spaces of the stone cairn before becoming embedded within the organic horizon of the underlying podzol soil (see table 5.5 for full sample information and figure 5.59 for radiocarbon plot). Again the lack of the charred micro-horizon visible in profiles 1 and 4 can be related to the irregular and random patterns in which forest fires spread.

5.4.4 Micromorphology

5.4.4.1 Profile 1

5.4.4.1.1 Description

According to the current landowner profile 1 is situated on the original home-field of the first settlers (Lindberg, *pers. comm*). Slide 1D was taken at a depth of 31cm; see figure 5.68 for soil profile drawing and location of slide and table 5.6 for the micromorphology description tables.

The B-horizon contains traces of E-horizon material as well as deeply decomposed organic material (9% amorphous organic), and has a moderately developed crumb microstructure. The mineral grains present reached size category 5 and had common silt capping up to size band 6; one of only two strata to reach silt capping width category 6 (see figures 5.60 and 5.61 for pictures), the other being micro-stratum 1 in profile 2, slide A, at the same site. The majority of the iron staining are found within the silt coatings; 20% of mineral material within this slide is iron stained.

Slide 1C was taken at a depth of 30cm and encompasses the B-horizon material seen in the lower slide but also a mixed A and E-horizon which is overlain by a secondary B-horizon. The lower B-horizon has the same properties seen in slide 1D but with marginally thinner silt capping (size band 3) and organic carbon coatings (size band 2); few and common in number respectively. There is also a higher percentage of fine organic material when compared to the B-horizon material in 1D (24% vs. 9%) and includes several traces of red and yellow turf material with very rare fragmented phytoliths; see figures 5.62 and 5.63 for photographs of phytoliths.

The overlying mixed A and E-horizon is a mixture of iron depleted E-horizon mineral grains (no iron staining on any of the mineral grains), fine organo mineral b-fabric material (25% of straum is organic), and a trace of partially dissolved micro-charcoal and spheroidal excremental pedofeatures. The stratum is overlain by a thin organic lamination, which has been very biologically active with a trace of charcoal which has been mixed randomly throughout an iron depleted organo-mineral material before the thin organic accumulation has formed. The upper B-horizon accumulation still has a higher organic content than the lower.

Slide 1B was taken at a depth of 15cm, from the bottom of the anthropogenic micro-stratum and consists of homogenised organo-mineral material with size 4 and 5 mineral grains (quartz and feldspar respectively) and pockets of E-horizon material. The organic content of this stratum is 37% but is composed of moderately to well decomposed organic material; the 10% spheroidal excremental material indicates a very biologically active soil which will also be partially responsible for the decomposed state of the organic material. The microstructure of this material is very homogenised with several traces of turf material (some with traces of phytoliths) located randomly throughout the slide as well as a single trace of manure and implies a high level of mixing; manure preserved by ferruginisation and contained fractured phytoliths. Within this mixed homogenised organo-mineral micromass is an intact seed, which has been identified as belonging to the *Plantago* family; see figures 5.64 and 5.65 for photographs (seed identified courtesy of Kristin Ismail-Meyer, *pers. comm*).

The mineral grain sizes within the stratum are very large and go against the traditional trend of decreasing mineral grain size with increasing proximity to the surface. The pockets of E-horizon material have sharp boundaries and have been recorded as micro-stratum 2 in the thin section description tables and have a much smaller maximum grain size than the surrounding material (size 2) and a very low organic content (7%). Carbon coatings up to size 2 were very common.

Slide 1A was taken at a depth of 6cm, further up the same anthropogenic topsoil as slide 1B, and is very similar to it in composition but much more homogenised; see figures

5.66 and 5.67 for photographs. The course material is very well accommodated with a coarse to fine ratio of 1/2. Organic carbon coatings remain common up to size.

5.4.4.1.2 Interpretation

Slide ID encompasses the B-horizon which itself contains traces of E-horizon material; evident from bleached, iron free pockets of disrupted material. The inclusion of pockets of disrupted E-horizon material in addition to the moderately developed crumb microstructure indicates disturbance which due to the depth of the sample, would be historic. Very large silt capping's up to size band 6 were present. There were discreet laminations within the coating which consisted of different gran sizes indicating that they have accumulated from at least two different periods; original coating has a finer grain size and is more compact than the outer, newer, layer which also has a higher organic content. The silt coatings are iron rich, indicating that they formed in a different environment and have retained the high iron level.

The depth and age of the micro-stratum, as indicated by the silt capping, in addition to the presence of the organic material, indicates that the disturbance was natural rather than anthropogenic and can be attributed to historic bioturbation, and root growth with burrowing fauna contributing to the mixing and introducing further organic material to the stratum. The common size 5 organic carbon coatings have been attributed to the depositional nature of carbon in B-horizon material as well as the high availability of amorphous organic material.

Slide 1C incorporates B-horizon material but has been partially mixed with E and A-horizon material. The lower B-horizon has the same properties as the B-horizon material seen in the lower slide but with thinner silt and carbon coatings which is too be expected with the decreasing depth. The mixed horizon material contains turf material with embedded fractured phytoliths which indicates mixing and disturbance; the phytoliths have become fractured from the mixing process.

The overlying A and E-horizon mixture, identified from the iron depleted mineral grains, b-fabric and organic content, has been disturbed through mixing. This is then overlain by a thin organic accumulation which has been biologically active and is reminiscent of the organic accumulation overlying a burning episode seen at the Sámi sites; charcoal which has been mixed randomly throughout the iron depleted organo-mineral material before the thin organic accumulation formed.

The two feasible explanations for this have been split into the charring activity either being natural or anthropogenic in origin. The natural hypothesis is that the light charring occurred on the original E-horizon (supported by the very rare size 3 silt capping's present on the mineral grains) as a result of a naturally induced forest fire which has occurred alongside a secondary process causing the mixed nature of these materials. As Hornmyr is inland in an area of known Sámi activity and herding and situated on one of the highest ridges in the area and with the inclusion of phytoliths it's possible that the mixing occurred from foraging reindeer during the winter period; which would fit with the reindeer's instinctive foraging techniques of migrating inland during the winter period and locating exposed high ridges where the snow cover is shallower and therefore the underlying vegetation is easier to reach. In this instance the thin overlying biologically active organic material could indicate the abandonment of the site as a grazing area. The anthropogenic and accepted hypothesis is that the past land surface was charred alongside the addition of turf material. This had then been covered with externally sourced mineral material from elsewhere in the site in a 'double digging' style of cultivation, thus providing a deeper rooting depth which is protected against the acidity associated with this style of cultivation which would impede the rooting depth (Delhaize and Ryan, 1995).

The upper B-horizon has a higher organic matter content than the lower, suggesting that the light charring in the A/E horizons has had a slight impact on the on-going organic accumulation at the site (27% vs. 24%) but otherwise the two strata are very similar; biological activity responsible for the very light mixing seen.

Slide 1B encompasses an organic rich biologically active soil which contains several turf fragments, manure deposits and a single *Plantago* seed. The soil has been heavily mixed and worked resulting in a homogenised microstructure. Due to this high level of mixing and the parenchymatic tissue present within the seed indicating it is reasonably fresh, it is likely that the seed has been translocated through bioturbation.

The size of the mineral grains within this stratum do not fit with the usual model of reducing grain size with increasing proximity to the surface soil and have a similar maximum grain size as seen in the lower B-horizon of slides 1C and 1D. The larger mineral grain size is also accompanied by larger and more frequent silt capping's (size 4 capping's common) which again fit with the capping's seen in the B-horizon of slide 1D. The pockets of E-horizon material have sharp boundaries and do not fit in any way with the surrounding material (20% less iron staining, smaller mineral grain sizes and associated coatings and significantly less organic material) they cannot have formed in situ, are classed as displaced and have been removed from an E-horizon elsewhere and added here. This indicates that the mineral grains are displaced and that they have originated elsewhere and have been added to the soil as part of the amendment process; to deepen the soil.

Slide 1A has been more intensively worked than the soil in slide 1B, with the organo-mineral material having less pore space and the course material being very well accommodated, rather than just partially accommodated as in 1B, and with a coarse to fine ratio of 1/2 compared to 2/1 in slide 1B. Even with a higher proportion of finer material than in slide 1B the maximum mineral grain size is still very large, reaching size band 5 with rare size 2 silt capping's, which fits with the diagnostic criteria of material from much deeper within the profile. E-horizon material also occurs in pockets as seen in slide 1B, but with more diffuse strata due to the level of working, with the same extremely weathered anorthoclase mineral grains seen in the E and B horizons being present throughout this slide further indicating the removal and re-deposition of deep mineral material from elsewhere in the site.

Overall, this is an anthropogenically deepened 'plaggen' type topsoil that has evidence of 'added' materials, which ranges from organic inputs such as turf material, charred organic material and manure to mineral material removed from the surrounding area, including from the E-horizon, which is evident as the pockets of E-horizon material as well as by the unusually large mineral grain sizes and accompanying silt coatings. The seed present in the lower left area of slide 1B has been identified as belonging to the *Plantago* family which has a large range of species including medicinal plants, as well as weeds, so it can be speculated that either this plant was grown specifically for its medicinal nature or it has grown as a weed on an exposed area of fertile soil. There is also evidence of the charring of the original surface vegetation. This has been followed by the addition of externally sourced mineral material, sourced from the surrounding area, including from the E-horizon; this is evident from the pockets of E-horizon material and the unusually large mineral grain sizes and accompanying silt coatings (size 4 capping's common). Other 'added' materials included inputs of turf material, charred organic material and manure.

This anthropogenic topsoil which has been worked to the point where everything, other than the large mineral grains, has been completely homogenised and contains the same 'added' materials as seen further down the profile indicating that the same land management technique has been employed throughout its use. This level of homogenisation may be related

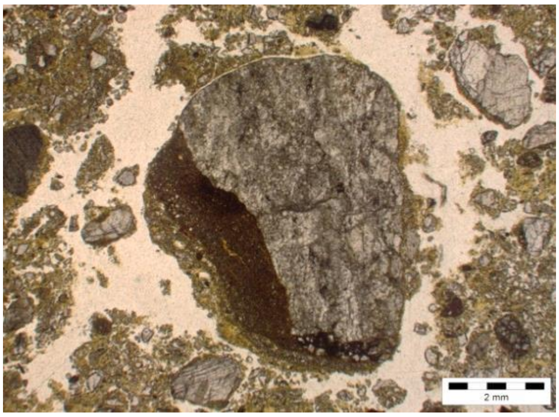


Figure 5.60: Layered size 6 capping PPL x1.25 mag

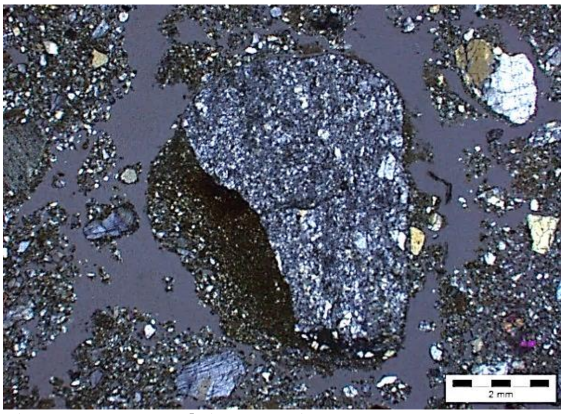


Figure 5.61: Layered size 6 capping XPL x1.25 mag

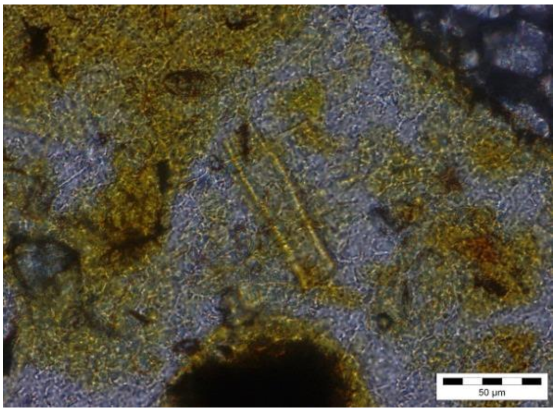


Figure 5.62: Fractured phytolith PPL x40 mag

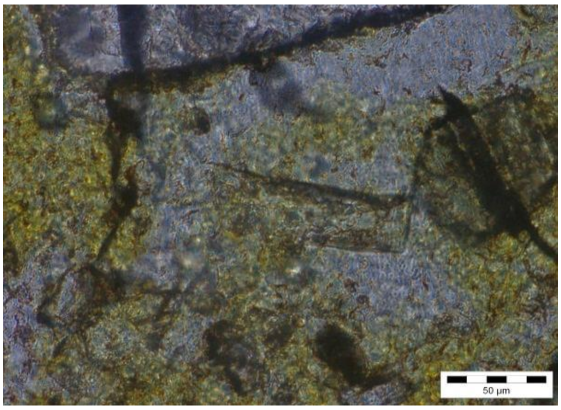


Figure 5.63: Fractured phytolith PPL x40 mag

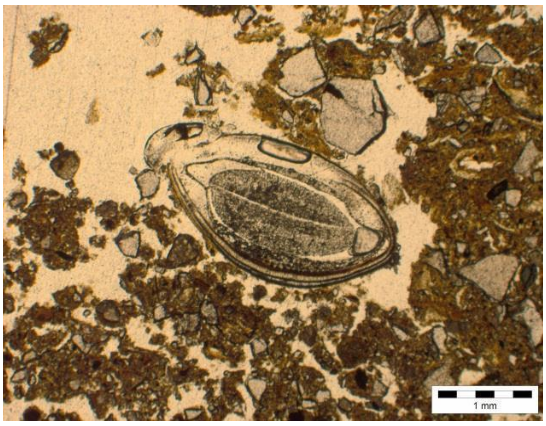


Figure 5.64: *Plantago* seed PPL x2 mag

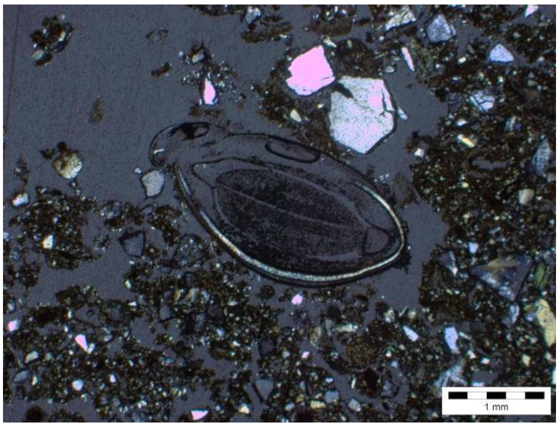


Figure 5.65: *Plantago* seed XPL x2 mag

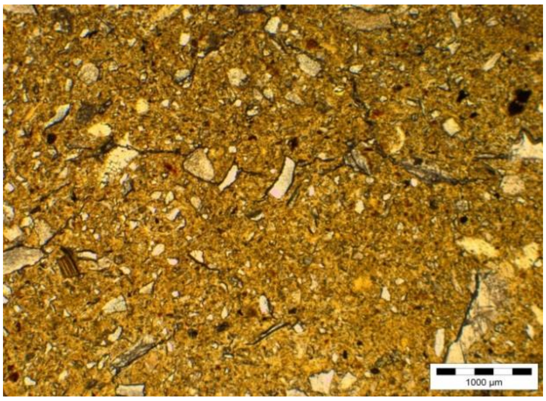


Figure 5.66: Deeply homogenised microstructure PPL x2mag

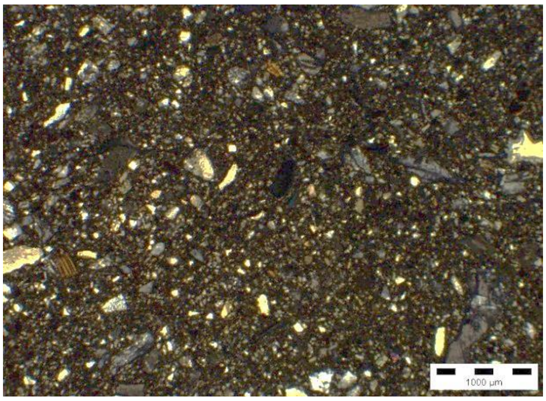


Figure 5.67: Deeply homogenised microstructure XPL x2 mag

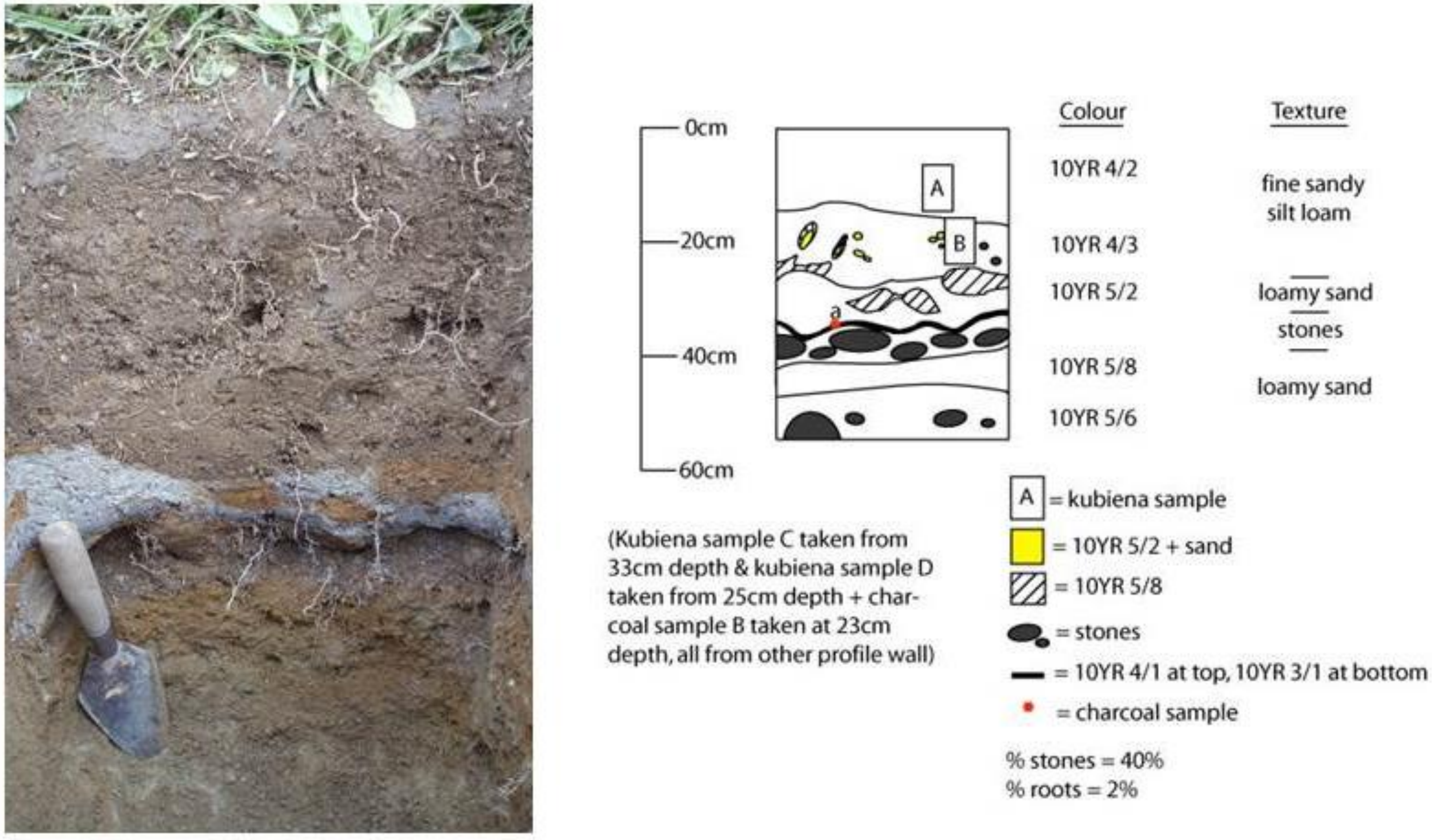


Figure 5.68: Photograph and soil profile diagram of profile 1

to recent farming activities as the field is still used for cultivation and modern day ploughs typically reach a depth of 15 to 30cm (Fathollahzadeh et al, 2009); slide taken at 6cm.

5.4.4.2 Profile 2

5.4.4.2.1 Description

Slide 2B was taken at a depth of 12cm; see figure 5.69 for soil profile drawing and location of slide and table 5.6 for the micromorphology description tables. The B-horizon is iron stained (20%) but the majority of this staining is of the fine organo-mineral material rather than the large mineral grains. There are several small, partially disintegrated patches of E-horizon material throughout; largest is in the lower right side of this strata (described as micro-strata three in the description tables). The B-horizon has traces of turf material located randomly throughout (few) and very few, size 3, silt capping's alongside as few organic carbon capping's up to size band 2.

The overlying micro-stratum is an anthropogenic topsoil but is different to that seen in profile 1. It has large mineral grains (up to size 5) with size 5 silt capping's (very few) as seen in profile 1 as well as the added organic materials of turf and charred organic material (no evidence of manuring) and the input of E-horizon material from elsewhere in the site.

Slide 2A was taken at a depth of 5cm and is a continuation of the anthropogenic topsoil seen in slide 2B but has a much more homogenised microstructure. The constitutions of this slide are similar to those in slide 2B with the exception of the afore mentioned homogeneity and introduced mineral grains. The mineral grains also reach size category 5 and have common silt capping up to size 6 but the highly altered anorthoclase mineral grains seen originally in the E and B horizons of profile 1, and then again as added material in the anthropogenic topsoil of profile 1, are also present within this slide.

5.4.4.2.2 Interpretation

Slide 2B encompasses the B-horizon and overlying anthropogenic topsoil. The B-horizon material fits with the typical iron stained and organic rich B-horizon material seen elsewhere. The inclusion of several small patches of partially disintegrated E-horizon material and turf fragments indicates not only the addition of mineral and organic material to the soil but also mixing; typical of soil preparation techniques such as plaggen management.

The overlying anthropogenically emended topsoil is different to that seen in profile 1. It consists of the same added turf material but has much larger mineral grains with large silt capping's. This indicates that since the large mineral grain and accompanying silt capping's indicate displaced mineral material from elsewhere in the site, that this mineral material has originated somewhere different to that added in profile 1. This means the amendment of the two profiles occurred independently of one another. As the microstructure is more open and less homogenised than that of profile 1, indicating that it has been less intensively worked, it suggests that the soil in profile 2 has been amended after that of profile 1. This also supports Lindberg's statement that profile 1 was the original homefield as by comparison with profile 2, it has received the initial input of material and has been more intensively amended and worked.

Slide 2A is a continuation of the anthropogenic material seen in the upper of slide 2B. It has a similar composition to the lower anthropogenic topsoil but a more homogenised structure, indicating the soil has been more intensively used over time, larger silt capping's, indicating that the added mineral material has continued but has been sourced from deeper within the neighbouring soils; the inclusion of anorthoclase minerals seen in the E and B-horizons of profile 1 is further indication of the addition of externally sourced mineral material from elsewhere in the site.

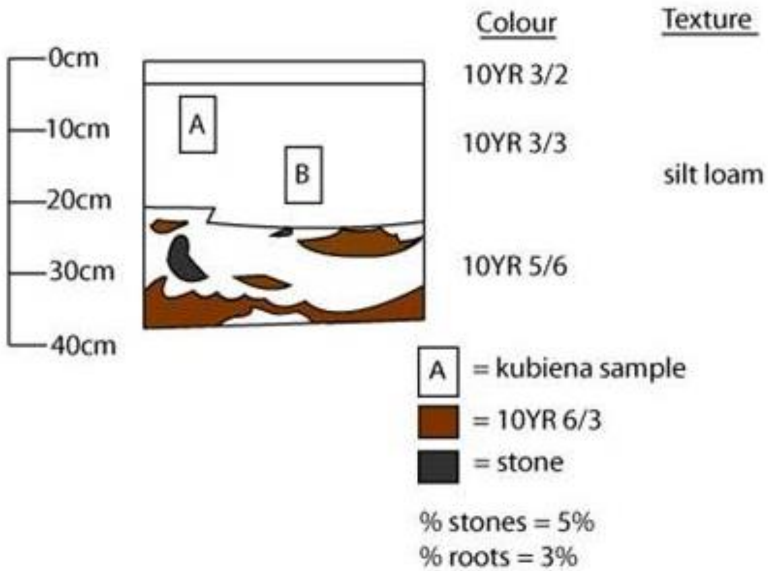


Figure 5.69: Photograph and soil profile diagram of profile 2

Overall, this profile shows a change in land management technique. The original mixing of the E and B horizons and addition of turf material represents the initial turning over of the turf material as the first step towards cultivation. This profile has then had plaggen type materials added to it in order to deepen and fertilise the topsoil but it was less intensively

5.4.4.3 Profile 3

5.4.4.3.1 Description

Slide 3B was taken at a depth of 17cm; see figure 5.72 for soil stratigraphy and location of slide, figure 5.73 for a photograph, drawing and digitised photograph of the slide and table 5.6 for the micromorphology description tables.

The B-horizon material is iron stained (25% of mineral material iron stained) but also organic rich (30% fine organic material) like the B-horizons seen at the Sámi sites. The silt capping's present are very few but large in size (size 5) with very few size 2 organic carbon coatings also present. Organic material is well decomposed.

The B-horizon is overlain by a past land surface (A-horizon) which has been charred. The boundary between the A-horizon, charred stratum, overlying E-horizon and underlying B-horizon is unclear due to eluviation processes. The charred material appears to have been at the top of the A-horizon material and occurs as a very thin but unbroken linear lamination and consists of micro-charcoal and partially charred tissue residue.

The charred past land surface is overlain by a partially developed E-horizon. The E-horizon has a low level of iron impregnation (5% of mineral material) but an elevated level of fine organic material (4%) and a very open nature (40% pore space) and is dissimilar to those seen in the Sámi and control samples.

The E-horizon is overlain by anthropogenic topsoil material, which is a mixture of externally sourced mineral material and organic turf and charcoal fragments. Large mineral grains and accompanying silt coatings are present throughout the topsoil. The soil itself is well mixed which has resulted in the boundaries between the soil horizons being indistinct.

Slide 3A was taken at a depth of 7cm and is further up the same anthropogenic topsoil as the upper stratum in slide 3B. The material here is very similar in composition to that seen in 3B but is more dense (20% void space vs. 30% in 3B). Added materials include turf (with trace of fractured phytoliths) and charcoal as well as externally sourced mineral material. The presence of charcoal is greater in this slide than in the same stratum in 3B (2% vs. trace) with a higher frequency and size of associated organic carbon coatings (few, size 3 in 3A compared to very few, size 2 in 3B). The turf material present within this slide also contains around 2% fine mineral material (<60μm).

5.4.4.3.2 Interpretation

Slide 3B encompasses, starting from the bottom of the slide, a B-horizon, charred A-horizon, E-horizon and then anthropogenic topsoil. The B-horizon is iron and organic rich with the organic material, although well decomposed, still retaining the morphology of roots, much like the B-horizons of the Sámi sites. This suggests that there has been no mixing within this stratum and that the organic coatings must be related to either disturbance or the input of charred material higher in the profile.

The B-horizon is overlain by a charred past land surface; indicated by the morphology and composition of organic charred material. The charred material is present in a thin, liner, unbroken deposit. The deposit includes micro charcoal through to charred tissue residue which suggests a low intensity burning of the surface vegetation. This linear deposition has undergone some transition in that several very discreet laminations appear, separated by E-horizon material, below the original and which has been interpreted as natural movement of micro-charcoal down profile rather than several very low intensity charring events. The charred stratum is overlain by a partially developed E-horizon. The E-horizon has a low level of iron impregnation and an elevated level of fine organic material with an open microstructure. This is unlike the E-horizons seen in the control and Sámi sites. There are no silt cappings within this stratum so the fine organic material could not have originated from mixing with the lower B-horizon but there are some iron rich siltstones which appear displaced. Another irregularity is the high level of pore space as although open structures can be associated with well-developed E-horizon material the void space from within these is from the well-developed lenticular microstructure whereas this stratum has a weakly developed crumb microstructure.

The E-horizon is overlain by the anthropogenically altered topsoil and is formed from a mixture of inputted mineral and organic components; evident through displaced mineral material and turf fragments. This material has been mixed to the point where boundaries between the small volumes of differing material are blurred and they are visually hard to see; differences most obvious in iron concentration, see figures 5.70 and 5.71 for images. The large mineral grains and their accompanying coatings (both size 3) occur throughout this stratum and imply that development into an anthropogenic topsoil occurred much later than at the previous profiles as deeply sourced material has been applied from the onset. The unusual E-horizon material may also be explained by this as up until this point charring of ground vegetation has been a natural process causing accumulation of organic material whereas here the charred past land surface stratum is overlain by the unusual E-horizon. It is being suggested that this E-horizon material has been deposited directly onto the charred material as part of a double digging technique; in order to form a deeper and more nutrient rich topsoil through the addition of charred organic material, whilst avoiding the acidification of the growing plant roots from the decaying charred materials (Macphail, R. *pers. comm*). This would explain the sudden increase in mineral grain size from 1 to 3 between the charred stratum and overlying E-horizon as well as the unusual microstructure and organic content which has then been further covered by material from even deeper in the removed soils profile providing the larger still mineral grains and accompanying silt capping's.

Slide 3A is the upper anthropogenic topsoil and is similar in configuration to the lower topsoil seen in slide 3B. It is however more dense with an increasing level of homogenisation with proximity to the surface. This indicates a continually increasing level of use over time as mixing breaks down the soil fabric resulting in a homogenised microstructure and intense use results in loss of pore space which leads to compaction. The same 'added' material of turf (with trace of fractured phytoliths) and charcoal as well as externally sourced mineral material can be found here, but like the upper levels of profiles 1 and 2 the greatly altered anorthoclase mineral grains seen in the deep E & B horizons of profile 1 are present here and indicate continuing addition of mineral material. The inputted turf material includes mineral material (2%) which indicates that it has been removed from a shallow area of turf, possibly an area which had been stripped previously i.e. a repeat extraction. Due to the location of the site high on a ledge the occurrence of deeper sourced mineral material with increasing proximity to the surface of the anthropogenic soils they have been added to indicates that surrounding material is limited and repeat extractions of both organic and mineral material must be carried out as there is no other feasible alternative.

Overall, this is a very interesting profile which shows a later and more hurried approach. This has been a natural podzol soil with the same charring of the surface vegetation as seen in profile 1 but it has immediately been covered with E-horizon material from elsewhere in the site and then again with deeper sourced and larger grained material. The organic carbon coatings seen in the B and E-horizons can be attributed to the charring and disturbance of the overlying strata. The subsequently formed anthropogenic strata has then been more actively used than the lower anthropogenic stratum at profiles 1 and 2, which suggest that it has been quickly formed out of necessity; perhaps new residents or expanding family. After its hasty development the management at this profile has been the same as the rest of the site with the same 'added' materials of turf, charcoal and mineral material with the same deeply sourced, extremely altered anorthoclase mineral grains present in the upper area of the anthropogenic stratum as is seen in profiles 1 and 2.

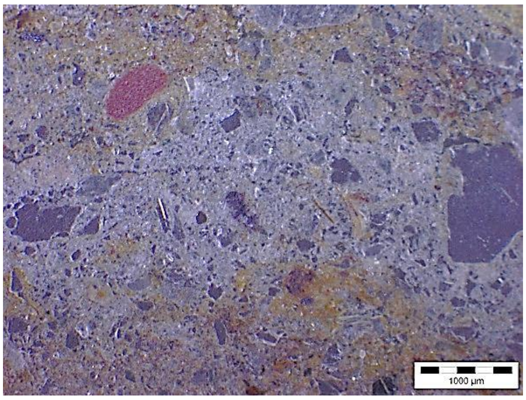


Figure 5.70: Patch of E-horizon material in anthropogenic stratum OIL x2 mag

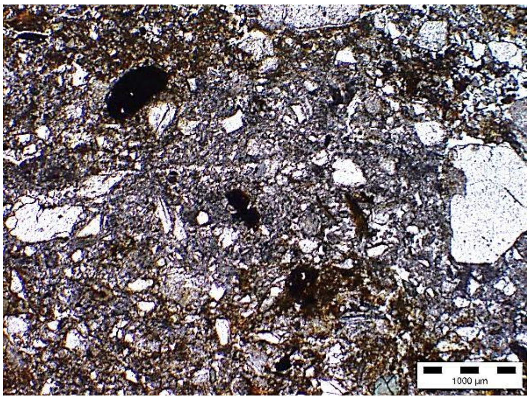


Figure 5.71: Patch of E-horizon material in anthropogenic stratum PPL x2 mag

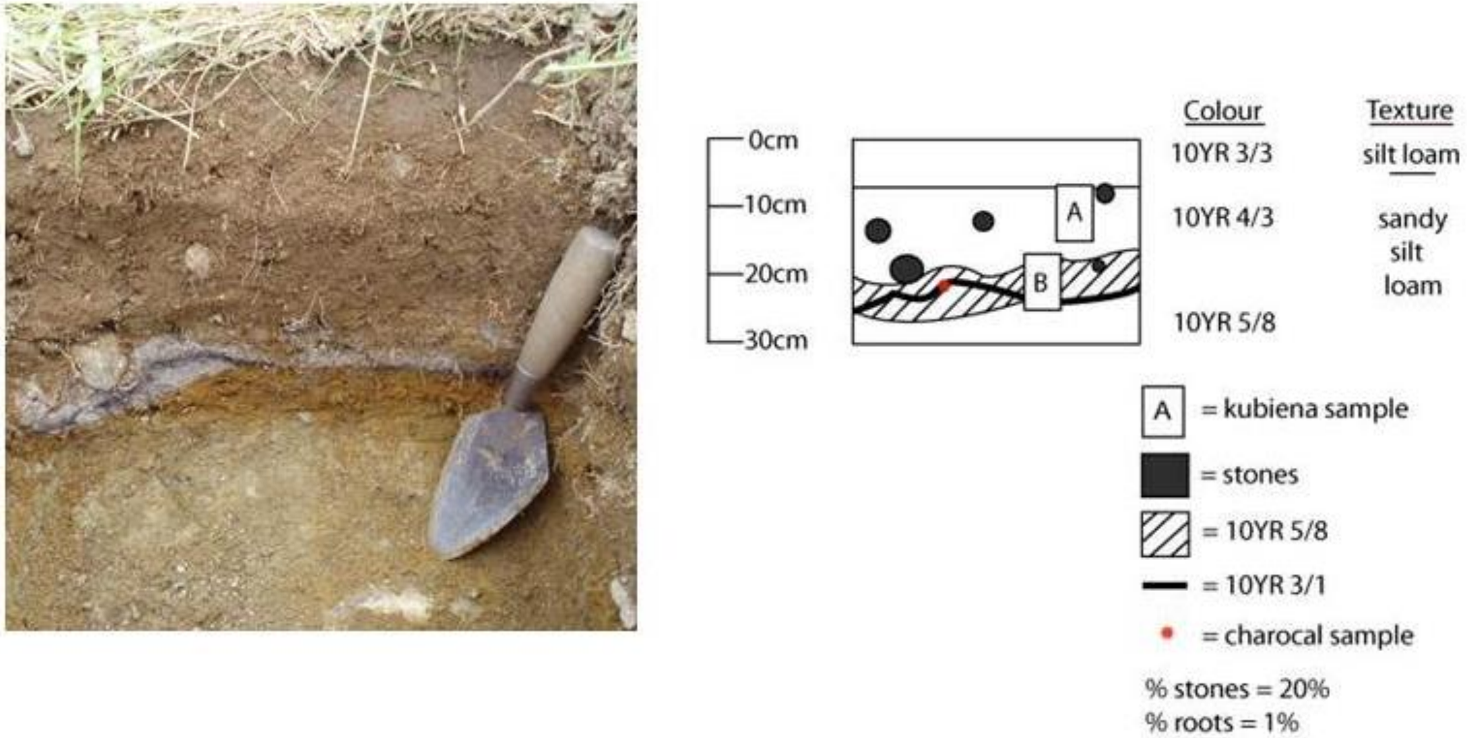
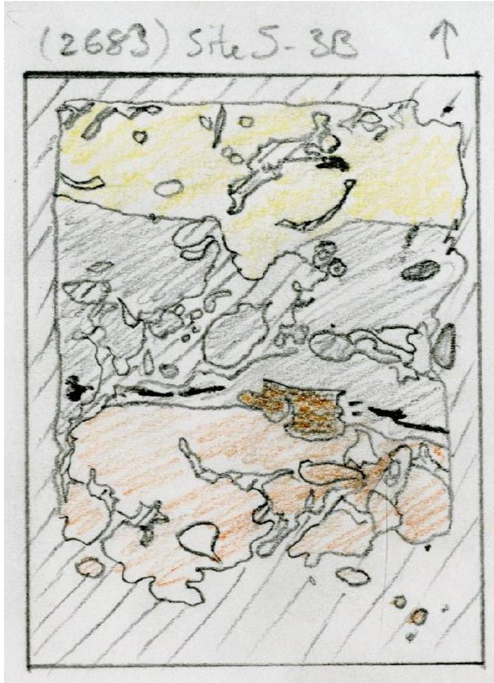


Figure 5.72: Photograph and soil profile diagram of profile 3

Photograph of slide

Digitised photograph of slide



Original drawing of slide

Figure 5.73: Photograph, diagram and digitised drawing of Hornmyr profile 3B

5.4.4.4 Profile 4

5.4.4.4.1 Description

Slide 4B was taken from underneath a large clearance cairn at a depth of 6cm; see figure 5.76 for soil profile drawing and location of slide and table 5.6 for the micromorphology description tables. Due to being taken underneath a clearance cairn this profile can be treated as a control sample i.e. how the soils were pre-settlement.

The B-horizon is open, organic rich and iron stained with very few, size 3 silt capping. There is no clear boundary between the B-horizon material and thin layer of E-horizon material just captured at the top of the slide.

Slide 4A was taken horizontally at a depth of 0cm and contains the E-horizon and overlying organic, natural, topsoil. There is a sharp boundary between the E and A-horizons; see figures 5.74 and 5.75 for photographs. The E-horizon has a well-developed lenticular microstructure further proving the lack of disturbance but does contain 5% charcoal.

The overlying organic rich A-horizon has a very low mineral content (10%, all size 1), and has been very biologically active, which is a stark contrast to the anthropogenically enhanced topsoils of profiles 1, 2 and 3.

5.4.4.4.2 Interpretation

Slide 4B contains the B-horizon with very fine patches of the overlying E-horizon towards the top of the slide. The B-horizon fits very well with the undisturbed Sámi B-horizons and subsequent control samples and shows no signs of disturbance; open, organic and iron rich with silt capping’s. Rare size 1 organic carbon coatings are present but these have not been attributed to anthropogenic disturbance due to the diminutive size and frequency and the lack of supporting evidence.

The sharp boundary between the E and A-horizons indicates that there has been no mixing between the two, either natural or anthropogenic. The E-horizon is well developed, which is further indication of its untouched state, and includes 5% charcoal. As the charcoal present is very small in form (size 1), partially dissolved and located near the surface of an undisturbed E-horizon it can be assumed that this charcoal has originated from the charring episodes of the surrounding area and has been deposited by aeolian processes before slowly dissolving and percolating down an open lenticular microstructure.

The A-horizon is very different to that seen in the previous profiles and is organic rich with a low mineral content and is very similar to the organic rich topsoil's at the Sámi sites; which confirms that there has been no anthropogenic disturbance or amendment to this profile. Overall, this control sample is an undisturbed picture of the pre-amendment soils with only a slight contamination from the windblown micro-charcoal.

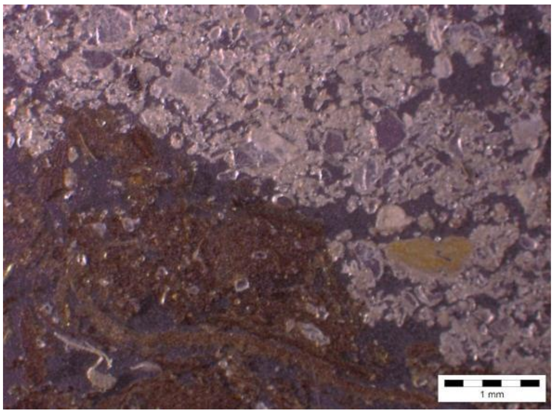


Figure 5.74: Sharp boundary between A and E horizons OIL x2 mag

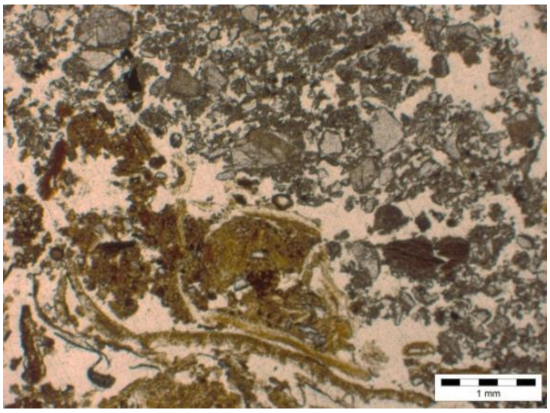


Figure 5.75: Sharp boundary between A and E horizons PPL x2 mag

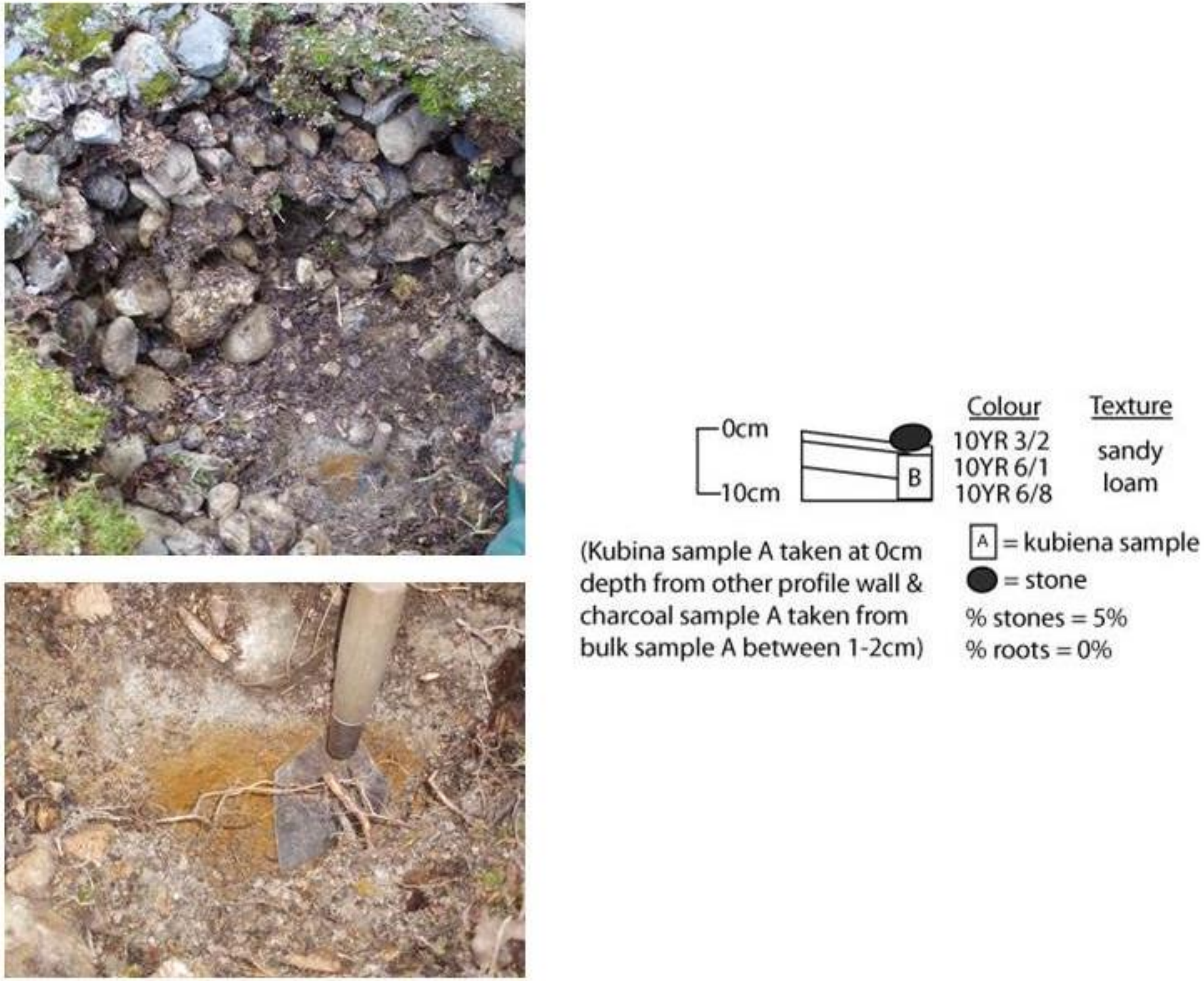


Figure 5.76: Photograph and soil profile diagram of profile 4

5.4.4.5 Profile 5

5.4.4.5.1 Description

Slide 5A was taken at a depth of 4cm from a waterlogged peat; see figure 5.77 for soil profile drawing and location of slide and table 5.6 for the micromorphology description tables.

It encompasses 5 alternating strata of organic and/or mineral accumulations. The organic strata are rich in pale yellow turf fragments and show no signs of disturbance. The mineral accumulations are themselves indicators of disturbance (from the surrounding area) and contain extremely altered anorthoclase mineral grains.

5.4.4.5.2 Interpretation

Slide 5A was taken from a waterlogged peat and encompasses 5 alternating organic and mineral strata. This was taken as a control sample and to see if any erosion material had accumulated here, but more interestingly this profile contains both the extremely altered anorthoclase grains seen in the upper anthropogenic soils in profile 1, 2 and 3 as well as the organic turf material present throughout all of the anthropogenic strata.

The pale yellow amorphous organic material present in all of the anthropogenic topsoil's is present within this peat as well as the turf material containing phytoliths (profile 1 and 3) and the organic turf material with fine mineral material (present in slide 3A). This indicates that the organic turf material applied to the anthropogenic topsoil's was extracted from the peat deposit such as this surrounding the site. The inclusion of the fine mineral material within some of the turf fragments in the anthropogenic soils indicates that repeat extractions have been carried out but that due to some mineral rich strata within the peats the percentage of turf to mineral material has varied depending on the micro-strata removed.

It is possible that the mineral rich micro-strata present have originated from eroding areas of the site but due to the depth of the peat accumulation as well as the presence of the same highly transformed anorthoclase mineral grains very deep in profile 1, it is very unlikely that the nearby areas eroded to that depth, accumulated on the peat and further peat accumulated above within the short period of occupation; a high level of energy would be needed for the aeolian removal and re-deposition of the mineral grains in micro-strata 3 and 5. Therefore the mineral accumulations within the peat deposits have been deemed as historic and not related to recent activity in or around the site.

5.4.4.6 Summary

Overall, the site has been a mixture of natural podzols and surrounding peat accumulations, which have been settled and amended by European settlers. The amendment included the initial clearing and preparation through stone removal (several very large clearance cairns still visible), burning of the surface vegetation, overturning of the turf material and addition of turf and mineral material from the surrounding peat and mineral soils. The addition of the organic and mineral material has continued throughout the duration of occupation with material being sourced and extracted from the same locations resulting in a shift in the typical pattern of smaller mineral grains with decreasing depth which stops at the past land surface and reverses to increasing mineral grain size with decreasing depth. Additional 'added' materials included a small amount of charred organic material and in the case of profile 1, a limited quantity of manure. Typically, the homogenous nature of the microstructure has increased with increasing proximity to the surface, as well as inclusions of deeper sourced mineral material from elsewhere in the site, indicating an increasing level of intensity over time. However profile 3, which is the shallowest of the 3 anthropogenic strata sampled, shows a high level of use and mixing immediately from the preparative stage i.e. the bottom of the micro-strata is as worked as the top. The thin charred strata is overlain by an accumulation of externally sourced E-horizon material before it has been mixed with turf material, and indicates that it has been prepared and used hastily. This indicates that as the settlement of Hornmyr expanded, the surrounding areas were prepared and used for cultivation much more quickly than seen in profiles 1 and 2 and indicates that profile 3 was a later addition to the cultivated land area. This fits with the plaggen model developed in chapter 2 in that the ploughing, addition of manure and a plaggen land management regime has led to the development of the cultural soil seen.

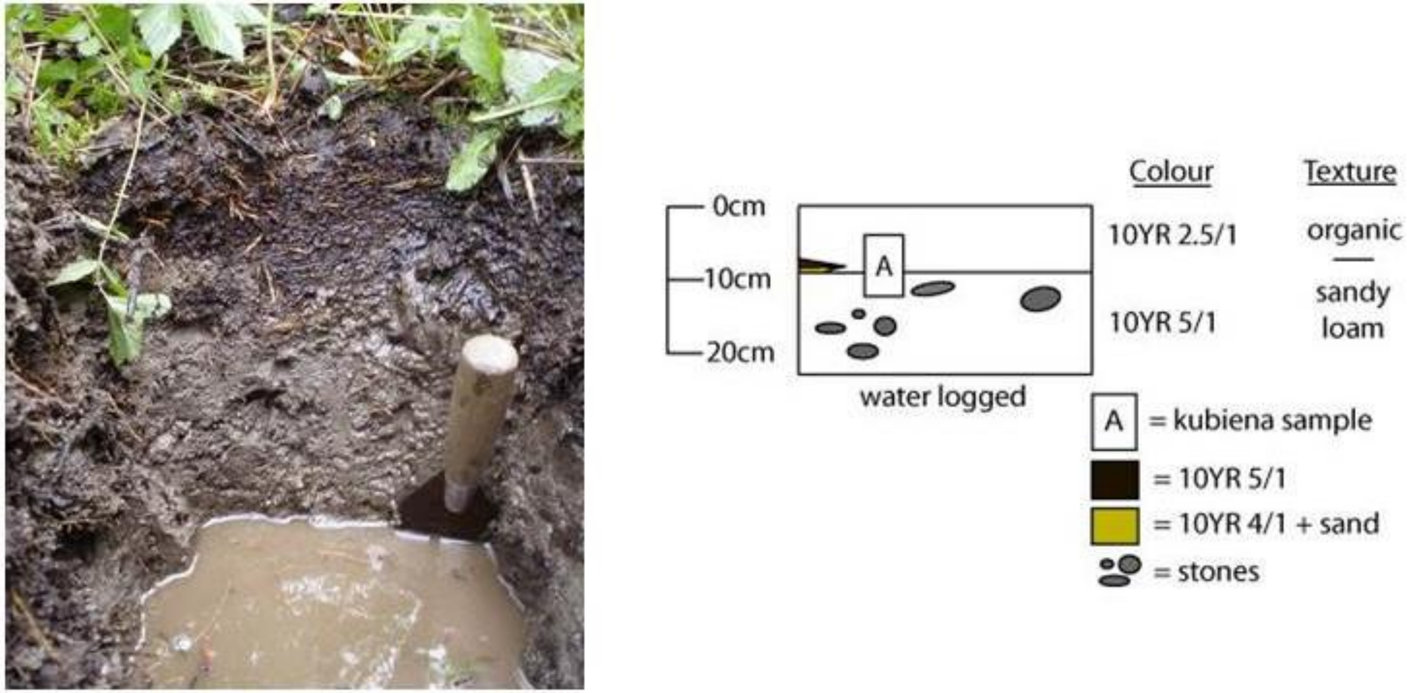


Figure 5.77: Photograph and soil profile diagram of profile 5

Table 5.6: Micromorphology descriptions tables for Hornmyr slides

			Coarse mineral material (>10µm)															Coarse Organic material (>10µm)								Fine Organic Material (<10µm)				Pedofeatures				Structure			
Profile	Micro-strata	Depth (cm)	Quartz %	Quartz maximum size	Feldspar %	Feldspar maximum size	Siltstone %	Siltstone maximum size	Mica %	Mica maximum size	Glauconite %	Arrangement of minerals	Fine mineral material (<60µm)	Silt coating frequency	Silt coating maximum size	Organic carbon coatings frequency	Organic carbon coating maximum	Organ residue	Tissue residue	Largest tissue residue (mm)	Lignified tissue	Sclerotia	% Charcoal	Largest charcoal	Cell residue	Amorphous black	Amorphous yellow	Amorphous brown	Amorphous red	Excremental (*Spheroidal*) 50-100µm	Fe impregnated mineral material %	Fe impregnated organic material %	% void space	Microstructure	Course material arrangement	Groundmass b fabric	C/F ratio
1A	1	6	20	4	10	4	15	5	5	2	2	SR	Grey + high order IC	2	2	3	5	t	t	100 x 50	t	-	t	1	t	2	10	15	t	t	15	-	20	Weak pedality , granular	Unsorted + accommodated	Single spaced fine enaulic. Orangey brown SS	1/2
	2		30	1	15	1	20	1	10	1	-	SR	Grey + low IC	-	-	2	5	-	t	50 x 50	-	-	-	-	t	-	t	5	t	-	t	-	20	Weak pedality, crumb	Unsorted, partially accommodated	Close fine enaulic, grey SS	3/1
1B	1	15	30	4	5	5	5	3	5	2	t	SR	Grey + high order IC	4	5	2	6	-	-	-	5	-	t	1	5	5	10	t	t	10	40	t	20	Weak pedality, crumb	Unsorted, partially accommodated	Single spaced fine enaulic, yellow grey SS	2/1
	2		30	2	15	2	15	2	5	1	-	SR	Grey + low IC	-	-	2	2	-	-	-	-	-	-	-	2	5	t	-	-	-	10	-	20	Weak pedality, crumb	Unsorted & well accommodated	Close fine enaulic, grey SS	2/1
1C	1	30	20	3	10	2	15	2	2	1	t	SR	Grey + low IC	3	1	2	5	-	-	-	-	-	t	1	5	2	10	5	t	5	20	-	25	Weak pedality, crumb	Unsorted, partially accommodated	Single spaced fine enaulic, yellow grey SS	2/1
	2		30	3	t	2	5	2	2	1	-	SR	Grey + low IC	3	1	2	5	-	-	-	5	1	t	1	5	5	5	5	t	t	-	-	30	Moderate developed crumb	Unsorted, un-accommodated	Close fine enaulic, grey SS	3/1
	3		25	4	10	4	10	2	5	1	t	SR	Grey + low IC	3	4	2	5	t	-	-	-	-	-	-	5	t	15	t	2	2	20	-	25	Moderate developed crumb	Unsorted, un-accommodated	Close fine enaulic, grey-yellow SS	2/1

Note: Micro-strata 1 + 2 of slide 1B contain a trace of fractured phytoliths
Micro stratum 3 of slide 1C contains very rare fractured phytoliths

			Coarse mineral material (>10µm)															Coarse Organic material (>10µm)								Fine Organic Material (<10µm)				Pedofeatures				Structure			
Profile	Micro-strata	Depth (cm)	Quartz %	Quartz maximum size	Feldspar %	Feldspar maximum size	Siltstone %	Siltstone maximum size	Mica %	Mica maximum size	Glauconite %	Arrangement of minerals	Fine mineral material (<60µm)	Silt coating frequency	Silt coating maximum size	Organic carbon coatings frequency	Organic carbon coating maximum	Organ residue	Tissue residue	Largest tissue residue (mm)	Lignified tissue	Sclerotia	% Charcoal	Largest charcoal	Cell residue	Amorphous black	Amorphous yellow	Amorphous brown	Amorphous red	Excremental (*Spheroidal*) 50-100µm	Fe impregnated mineral material %	Fe impregnated organic material %	% void space	Microstructure	Course material arrangement	Groundmass b fabric	C/F ratio
1D	1	31	20	5	10	3	10	5	5	1	-	SR	Grey + low IC	6	5	5	5	-	-	-	-	-	-	-	t	t	5	2	2	-	20	-	40	Moderate developed crumb	Unsorted, partially accommodated	Close fine enaulic, grey-yellow SS	2/1
2A	1	5	25	5	10	4	10	3	t	2	2	SR	Grey + low IC	6	5	2	5	2	2	2	5	-	t	1	5	2	5	t	t	10	20	-	25	Weak pedality, crumb	Unsorted, partially accommodated	Close fine enaulic, grey-yellow SS	2/1
2B	1	12	20	5	10	3	10	3	5	3	2	SR	Grey + low IC	5	3	2	4	-	-	-	2	-	2	1	5	2	2	5	t	10	20	-	25	Weak pedality, crumb	Unsorted, partially accommodated	Close fine enaulic, grey-yellow SS	2/1
	2		20	3	10	3	10	3	2	1	t	SR	Grey + low IC	3	3	2	4	-	-	-	-	-	-	-	10	t	10	10	-	-	20	-	25	Weak pedality, crumb	Unsorted, partially accommodated	Close fine enaulic, grey-yellow SS	2/1
	3		30	2	10	2	5	2	5	1	t	SR	Grey + low IC	4	4	2	3	-	-	-	t	-	-	-	t	t	t	-	-	-	t	-	30	Moderate developed pedality, lenticular	Unsorted, partially accommodated	Single spaced porphyric, grey SS	1/2
3A	A	7	20	5	10	3	5	2	5	2	t	SR	Grey + low IC	5	4	3	4	5	2	100 x 50	-	-	2	3	10	2	2	t	2	5	20	-	30	Moderate developed pedality, granular	Unsorted & accommodated	Single spaced fine enaulic, orangey brown SS	2/1
3B	1	17	20	3	15	2	15	2	5	1	t	SR	Grey + low IC	3	2	2	3	-	5	50 x 50	t	-	t	1	5	5	5	2	5	-	15	-	20	Weak pedality, granular	Un sorted & well accommodated	Single spaced fine enaulic, orangey brown SS	3/1

Note: Slide 3A contains a trace of fractured phytoliths

				Coarse mineral material (>10µm)														Coarse Organic material (>10µm)								Fine Organic Material (<10µm)				Pedofeatures				Structure			
Profile	Micro-strata	Depth (cm)	Quartz %	Quartz maximum size	Feldspar %	Feldspar maximum size	Siltstone %	Siltstone maximum size	Mica %	Mica maximum size	Glauconite %	Arrangement of minerals	Fine mineral material (<60µm)	Silt coating frequency	Silt coating maximum size	Organic carbon coatings frequency	Organic carbon coating maximum	Organ residue	Tissue residue	Largest tissue residue (mm)	Lignified tissue	Sclerotia	% Charcoal	Largest charcoal	Cell residue	Amorphous black	Amorphous yellow	Amorphous brown	Amorphous red	Excremental (*Spheroidal*) 50-100µm	Fe impregnated mineral material %	Fe impregnated organic material %	% void space	Microstructure	Course material arrangement	Groundmass b fabric	C/F ratio
	2		30	3	15	2	10	2	t	1	t	SR	Grey + low IC	-	-	2	3	-	-	-	-	-	-	-	-	t	2	2	t	-	5	-	40	Weak pedality, crumb	Unsorted & accommodated	Close fine enaulic, grey SS	2/1
	3		25	1	15	1	5	1	t	1	-	SR	Grey + low IC	-	-	-	-	-	15	1000 x 500	5	2	5	4	-	10	t	t	-	-	t	-	20	Weak pedality, granular	Well sorted & accommodated	Close fine enaulic, grey SS	2/1
	4		25	3	10	3	5	3	5	1	-	SR	Grey + low IC	5	3	2	3	-	-	-	-	-	-	-	10	t	15	5	t	-	25	-	30	Weak pedality, granular	Unsorted & accommodated	Close fine enaulic, grey-yellow SS	3/1
4A	1	0	10	1	t	1	T	1	t	1	-	SR	Grey + low IC	-	-	2	1	5	10	200 x 50	5	-	-	-	10	t	t	t	t	15	T	10	50	Well developed, crumb	Partially sorted, un-accommodated	Double spaced equal enaulic. Orange SS	4/1
	2		30	2	10	2	20	2	t	2	t	SR	Grey + low IC	-	-	1	1	5	-	-	-	1	5	1	t	5	t	t	t	t	5	-	20	Well-developed lenticular	Partially sorted & accommodated	Single spaced fine enaulic, grey SS	2/1
4B	1	6	25	2	15	2	20	1	t	1	t	SR	Grey + low IC	-	-	2	2	5	-	-	-	-	-	-	-	t	t	5	t	-	10	-	20	Weak pedality, crumb	Partially accommodated & sorted	Close fine enaulic, grey SS	3/1
	2		25	3	5	3	10	3	5	2	t	SR	Grey + low IC	3	3	1	2	t	5	150 x 50	-	-	-	-	5	2	t	2	t	20	50	-	20	Weak pedality, crumb	Partially accommodated & unsorted	Single spaced fine enaulic, yell/grey SS	3/1

				Coarse mineral material (>10µm)														Coarse Organic material (>10µm)								Fine Organic Material (<10µm)				Pedofeatures				Structure			
Profile	Micro-strata	Depth (cm)	Quartz %	Quartz maximum size	Feldspar %	Feldspar maximum size	Siltstone %	Siltstone maximum size	Mica %	Mica maximum size	Glauconite %	Arrangement of minerals	Fine mineral material (<60µm)	Silt coating frequency	Silt coating maximum size	Organic carbon coatings frequency	Organic carbon coating maximum	Organ residue	Tissue residue	Largest tissue residue (mm)	Lignified tissue	Sclerotia	% Charcoal	Largest charcoal	Cell residue	Amorphous black	Amorphous yellow	Amorphous brown	Amorphous red	Excremental (*Spheroidal*) 50-100µm	Fe impregnated mineral material %	Fe impregnated organic material %	% void space	Microstructure	Course material arrangement	Groundmass b fabric	C/F ratio
5A	1	4	5	1	-	-	-	-	-	-	-	SR	Grey + low IC	-	-	1	2	20	10	125 x 100	-	-	-	-	10	-	30	5	t	t	-	5	15	Weak pedality, granular	Well sorted & accommodated	Double spaced porphyric, orange SS	1/3
	2		25	1	5	1	t	1	t	1	-	SR	Grey + low IC	-	-	2	3	5	5	50 x 50	-	2	-	-	10	5	20	2	5	-	T	5	15	Weak pedality, granular	Well sorted & accommodated	Single spaced porphyric, yellow SS	1/1
	3		30	2	10	1	15	1	t	1	t	SR	Grey + blue & yellow IC	-	-	2	2	t	2	200 x 50	t	-	-	-	10	2	5	5	2	t	2	-	10	Weak pedality, granular	Well sorted & accommodated	Single spaced porphyric, yellow SS	3/1
	4		10	1	-	-	-	-	t	1	-	SR	Grey + low IC	-	-	2	2	5	5	250 x 200	t	-	-	-	20	15	10	10	5	t	-	t	10	Weak pedality, granular	Well sorted & accommodated	Single spaced porphyric, yellow SS	1/2
	5		25	4	10	2	15	1	2	1	t	SR	Grey + low IC	-	-	1	2	5	5	100 x 50	t	30	-	-	5	2	10	2	2	-	2	t	20	Weak pedality, granular	Partially sorted, well accommodated	Single spaced porphyric, yellow SS	2/1

5.4.5 Chemical analysis

5.4.5.1 pH

The pH values show for the European sites again contradict the pattern seen in the Sámi, podzol samples; profiles 4 – 6 are control samples with profile 4 being a podzol underneath a clearance cairn and profiles 5 and 6 being organic accumulations (see figure 5.78). Interestingly the pH values for profile 1, the original home-field, are very high and remain constant throughout. This indicates that given enough input the decreased pH associated with anthropogenic topsoils overlying podzol soils can actually influence the pH of the underlying horizons, resulting in decreased acidity throughout the profile.

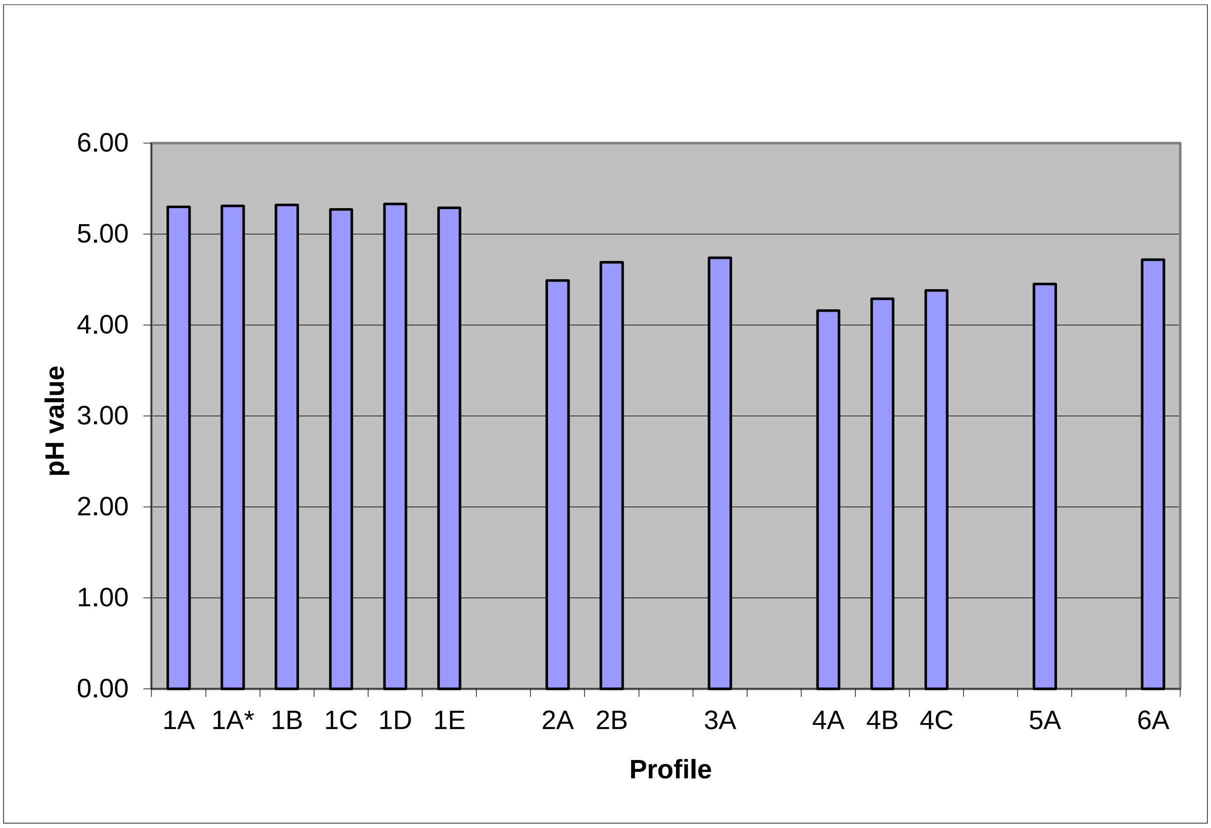


Figure 5.78: Bar graph showing pH values for all profiles at Hornmyr

5.4.5.2 Magnetic susceptibility

The magnetic values for Hornmyr are all stable but with a large peak at profile 4 (see figure 5.79). Profile 4 was located underneath a clearance cairn and is one of the control samples for the site; profile 5 is an undisturbed peat deposit. Due to the large difference in magnetic values between the two control samples a straight forward interpretation is difficult. It has therefore been surmised that since the base value in profile 5 is very low with the values for the amended soils falling mid-way between it and the clearance cairn sample, that profile 4 has been subjected to the aeolian input of charred material from the surrounding active cultural soils. As this profile has remained undisturbed the magnetic signature has not been diluted through the addition of 'added' materials.

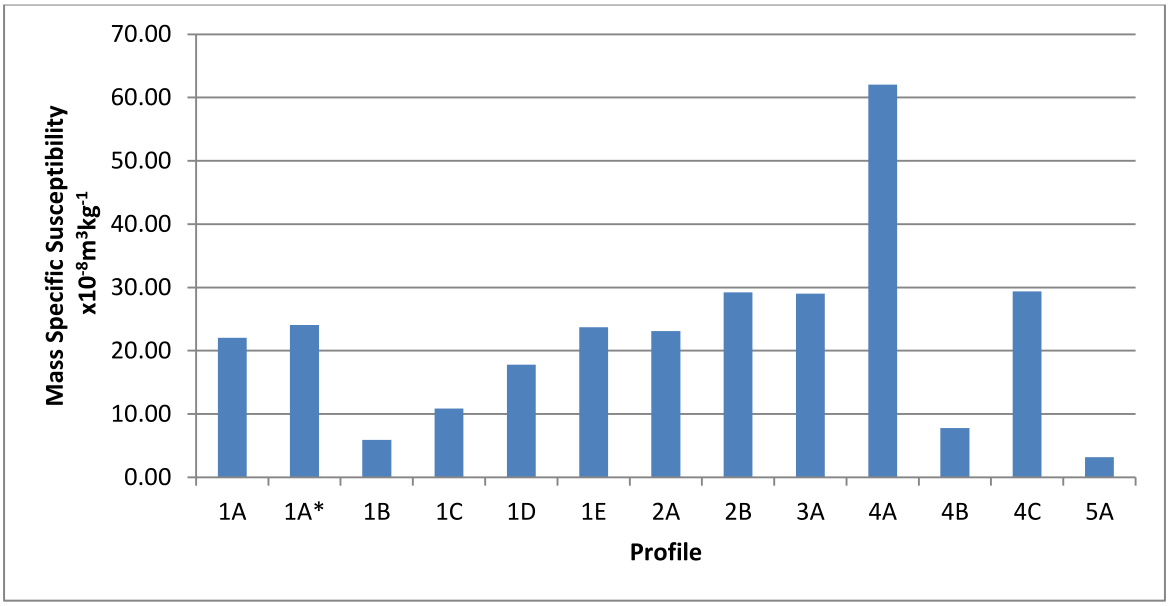


Figure 5.79: Mass Specific Magnetic Susceptibility values for Hornmyr

5.4.5.3 SEM analysis

One way ANOVA's were carried out comparing each soil horizon from each of the three sites. The phosphorous levels in the anthropogenic topsoil's at the three sites were statistically distinct from one another (see figure 5.80). As the base soil at each site is podzolic this spread in values is most likely linked to the land management techniques employed at each site i.e. the applied materials.

```
Source   DF      SS      MS      F      P
Site      6  1.2490  0.2082  11.85  0.000
Error    20  0.3515  0.0176
Total    26  1.6005

S = 0.1326   R-Sq = 78.04%   R-Sq(adj) = 71.45%

                           Individual 95% CIs For Mean Based on
                           Pooled StDev
Level         N    Mean   StDev  ---------+---------+---------+---------+
Hornmyr       9  0.0578  0.0335          (--*--)
Gammelhemmet  6  0.3400  0.2425                   (--*---)
Kåddis        3  0.6700  0.1500                            (----*-----)
                                 ---------+---------+---------+---------+
                                       0.00      0.30      0.60      0.90
```

Figure 5.80: Output from Tukey's multiple comparisons regarding the Phosphorous levels in the topsoil at Hornmyr, Gammelhemmet and Kåddis

Interestingly the potassium and iron levels were significantly different at Hornmyr than at the other European sites; with the values at the other two sites appearing quite similar (see figures 5.81 and 5.82). This may again be linked to differing approaches in added materials. For example the addition of material from elsewhere on the site, at Hornmyr there is evidence of the mineral rich peat behind the site being added to the topsoil whereas there was no equivalent peaty material to be added at the other sites. This is supported by the difference in the chloride levels in the organic horizons with chloride being indicative of decomposing organic material (Keppler and Biester, 2003); see figure 5.83.

```
Source   DF      SS      MS     F      P
Site      6  0.7546  0.1258  5.32  0.002
Error    20  0.4731  0.0237
Total    26  1.2277

S = 0.1538   R-Sq = 61.46%   R-Sq(adj) = 49.90%

                           Individual 95% CIs For Mean Based on
                           Pooled StDev
Level         N    Mean   StDev  ---------+---------+---------+---------+
Hornmyr       9  0.4822  0.1682                         (---*----)
Gammelhemmet  6  0.1850  0.0857             (----*-----)
Kåddis        3  0.2600  0.0608              (------*-------)
                                 ---------+---------+---------+---------+
                                      0.00      0.25      0.50      0.75
```

Figure 5.81: Output from Tukey's multiple comparisons regarding the Potassium levels in the topsoil at Hornmyr, Gammelhemmet and Kåddis

```
Source   DF      SS      MS     F      P
Site      6  1.9419  0.3236  3.32  0.020
Error    20  1.9494  0.0975
Total    26  3.8913

S = 0.3122   R-Sq = 49.90%   R-Sq(adj) = 34.87%

                           Individual 95% CIs For Mean Based on
                           Pooled StDev
Level         N    Mean   StDev   --+---------+---------+---------+-------
Hornmyr       9  0.6422  0.2072                          (----*----)
Gammelhemmet  6  0.0800  0.0486          (------*------)
Kåddis        3  0.0133  0.0231      (--------*---------)
                                  --+---------+---------+---------+-------
                                  -0.40      0.00      0.40      0.80
```

Figure 5.82: Output from Tukey's multiple comparisons regarding the Iron levels in the topsoil at Hornmyr, Gammelhemmet and Kåddis

```
Source   DF        SS        MS     F      P
Site      6  0.026221  0.004370  5.57  0.001
Error    27  0.021179  0.000784
Total    33  0.047400

S = 0.02801   R-Sq = 55.32%   R-Sq(adj) = 45.39%

                            Individual 95% CIs For Mean Based on
                            Pooled StDev
Level         N     Mean    StDev  -----+---------+---------+---------+----
Hornmyr       4  0.00750  0.01500  (------*------)
Gammelhemmet  3  0.04667  0.04509          (--------*-------)
Kåddis        6  0.06833  0.02994                  (-----*-----)
                                   -----+---------+---------+---------+----
                                      0.000     0.040     0.080     0.120
```

Figure 5.83: Output from Tukey's multiple comparisons regarding the Chloride levels in the O horizons at Hornmyr, Gammelhemmet and Kåddis

5.4.6 Summary

The combined analysis gives us more evidence on the preparation activities immediately following settlement which were limited or not clear in the earlier sites. The visible clearance cairns and overturned turf fit with the extension of the tax free period identified in the background information sub-section and demonstrate to an extent how much preparation work was needed prior to the addition of materials to form the deeper, more nutrient rich topsoil needed for cultivation.

Hornmyr fits with the emerging high impact, cultivation based picture seen at Kåddis and Gammelhemmet. The high level of amendment and input materials is evident throughout the analysis including the addition of deeply sourced mineral material to add depth to the topsoil as seen at Gammelhemmet. The field, micromorphological and chemical analysis all indicate a highly worked soil, perhaps more so than at the previous European sites. The complete change in soil pH throughout profile 1 is quite different to the poorly decreased acidity levels in the lower horizons at the previous sites and again indicates the high level of input into the home-field.

The historical evidence of the extended tax free period due to the stoney nature of the site is reinforced by the large clearance cairns seen in the field evidence. The over turned turf as part of the supporting land clearance and preparation on the site when first settled was not visible elsewhere and has likely been preserved due to the fast soil accumulation rate on site preventing the farming tools from further disturbing the buried, over-turned horizons.

The cultural indicators for the site support those identified in the earlier two sites and highlights the importance of field evidence when identifying European sites; the clearance cairns, deep topsoil and overturned underlying profiles are all strong evidence of preparation activities. The decrease in acidity in the amended topsoil compared to the natural soil has already been identified as a cultural indictor of European cultivation however, further work looking at the impact on the acidity of the underlying horizons could help to identify the degree of amendment to the soil or a difference in inputted materials.

5.5 Synthesis

A clear picture of the high impact European occupation had on the landscape is emerging from the individual analysis of the sites, however, comparative analysis has also been carried out to supplement this understanding. Environmental information which may help understand why the site was chosen through to comparative statistics has been carried out in the following sub-sections to look for further patterns indicative of European activity.

5.5.1 Origin of charcoal samples

The origin of the charcoal dated for each site has been graphed to identify any introduced, i.e. foreign wood species, as well as to show any differences between the sites; see figure 5.66. As only selected material was dated and therefore identified this data is just a representation of the species spread at each site. Nevertheless the graph has identified a mosaic vegetation cover at Hornmyr when compared to the uniform origin of the charcoal at the other European sites (see figure 5.84). This indicates two things, firstly that the charred organic material identified in the micromorphological analysis of Gammelhemmet and Kåddis has come from the charring of *Pinus Sylvestris*, but also that the opening up of the wood cover at Hornmyr has resulted in a change to a more mosaic ground cover which acts as evidence of cultivation on site.

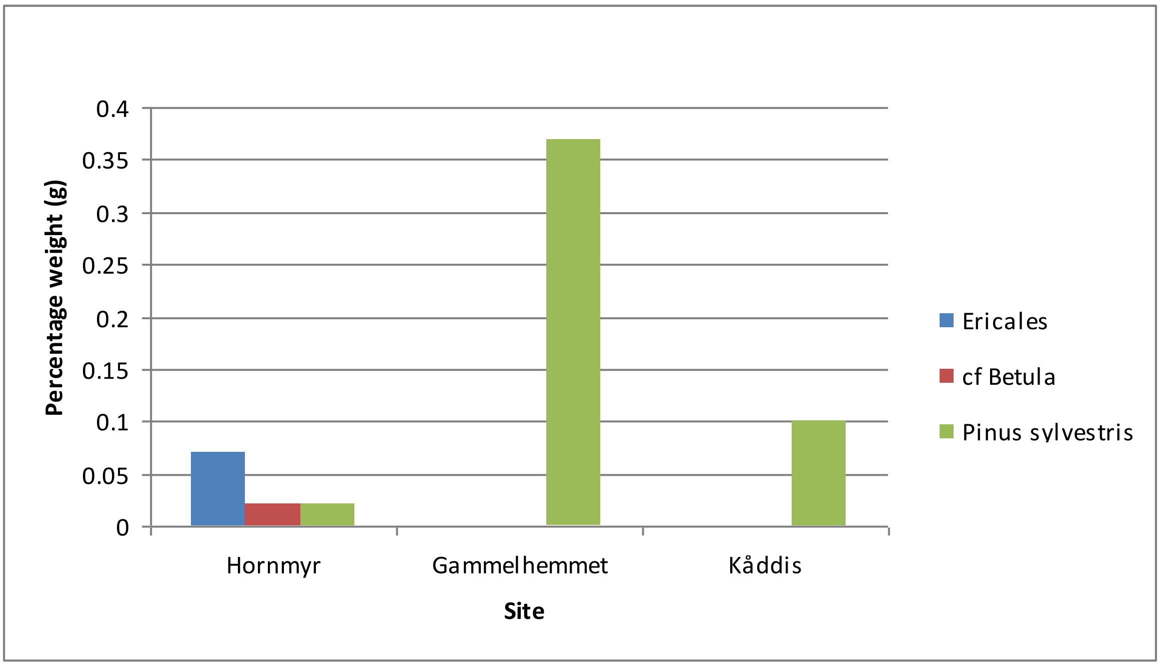


Figure 5.84: The origin of the charcoal samples dated from Hornmyr, Gammelhemmet and Kåddis

5.5.2 Coatings

The coatings observed in the micromorphology slides, both silt and carbon, are recorded in the description tables and discussed in the relevant micromorphology write up but have also been graphed so that any patterns or irregularities can be seen; there are not enough silt coatings for statistical analysis and statistical analysis of the carbon coatings did not return any significant results at a 95% confidence level. The coatings were recorded and measured according to size tables during the micromorphological analysis of the thin section slides and as not all slides contained either or types of coatings the sample numbers vary greatly from horizon to horizon and site to site; the key showing the equivalent percentages and sizes for the coatings is listed in table 5.7.

Table 5.7: Key for silt and carbon coating sizes and occurrence levels

Organic carbon coating size:	Occurrence levels:	Silt coating size:
<10µm = 1	Very rare (trace) = 1	<250µm = 1
10-25µm = 2	Rare (trace -2%) = 2	250-500µm = 2
25-40µm = 3	Very few (2-5%) = 3	500-750µm = 3
40-60µm = 4	Few (5-15%) = 4	750-1000µm = 4
60-80µm = 5	Common (15-30%) = 5	1000-2000µm = 5
>80µm = 6	Frequent (30-50%) = 6	>2000µm = 6

Figure 5.67 shows the silt and carbon coatings, size and level of occurrence, for all anthropogenic A-horizons at the European sites as well as from the control sample A-horizons. The high occurrence rate and large size of the periglacially formed silt capping's at site 5 is evidence of the input of B and C horizon material sourced from elsewhere on site in order to deepen the anthropogenic topsoil. This is confirmed by the lack of silt capping's in the control A-horizon samples; this is reflected in profiles 2 and 4 at Gammelhemmet. There are no silt capping's present at Kåddis but as there were no silt capping's present in the lower horizons of the anthropogenic profiles this is connected to the fluvial parent material rather than indicating a lack of applied mineral material.

The size and occurrence of organic carbon coatings has been linked to the abundance of carbon from burning events, throughout this and the Sámi landscape chapters, rather than solely indicating disturbance. However it is evident from figure 5.85 that the average size and occurrence of organic carbon coating in a natural setting even with frequent forest fires is 2 so site 5 has significantly more coatings, even if a similar size, with sites 6 and 7 only having slightly more coatings; although there is a peak at profile 3, site 7 where there is an occurrence level of 5. This could be related to the mixed nature of the anthropogenic soils in that the carbon material is constantly being muddled up within the profile allowing for carbon coatings to form above the burning event, it could be related to the continued input of charred material at several of the profiles or it could simply be an indication of disturbance.

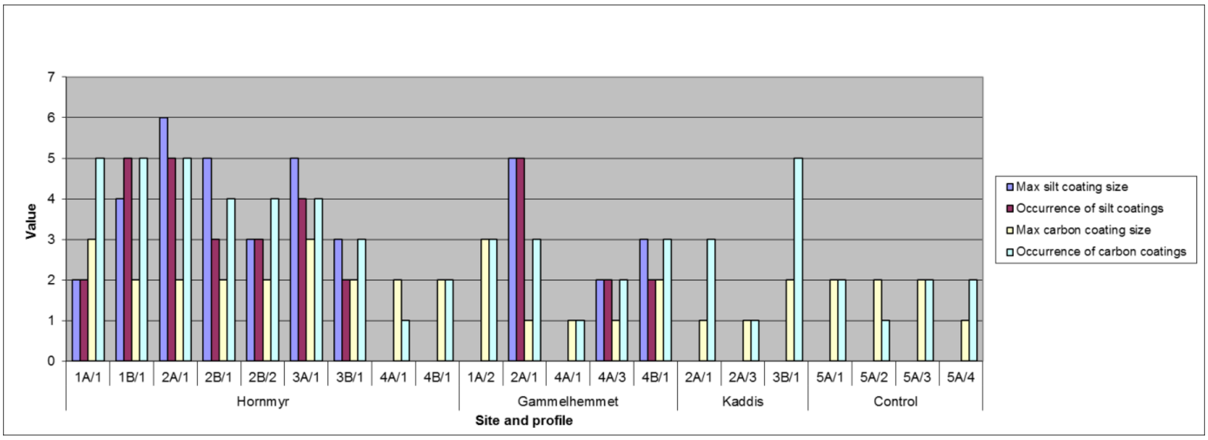


Figure 5.85: Bar graph showing maximum size & occurrence of silt and carbon coatings in the anthropogenic A-horizons of the European sites

Table 5.8 shows the average A-horizon value for the European sites as well as the control average for comparison. The silt coating size and occurrence in comparison to the lack of any in the control samples is further indication of the outsourcing of mineral material from the lower horizons of hinterland and unused soils. The carbon coating size is similar across the board however there is an elevation in occurrence as indicated by the graph in figure 5.85 above.

Table 5.8: Averages of maximum size & occurrence of silt and carbon coatings in the A-horizons of the European sites and their subsequent control samples; averages are of the size and occurrence levels as per the key table (5.7)

	Max silt coating size	Occurrence of silt coatings	Max carbon coating size	Occurrence of carbon coatings
Average European:	2.2	1.9	2.3	3.9
Average control:	0.0	0.0	1.8	1.8

Figure 5.86 shows the silt and carbon coatings, size and occurrence level, for all E-horizons where again there are silt capping's at two of the European sites. The size and occurrence of the capping's is less than in the A-horizon and fits with the reducing size and occurrence with decreasing depth anticipated in natural soils which, as the occurrence rate and size increases in the overlying A-horizon, further illustrates the addition of the deeply sourced mineral material to the A-horizon.

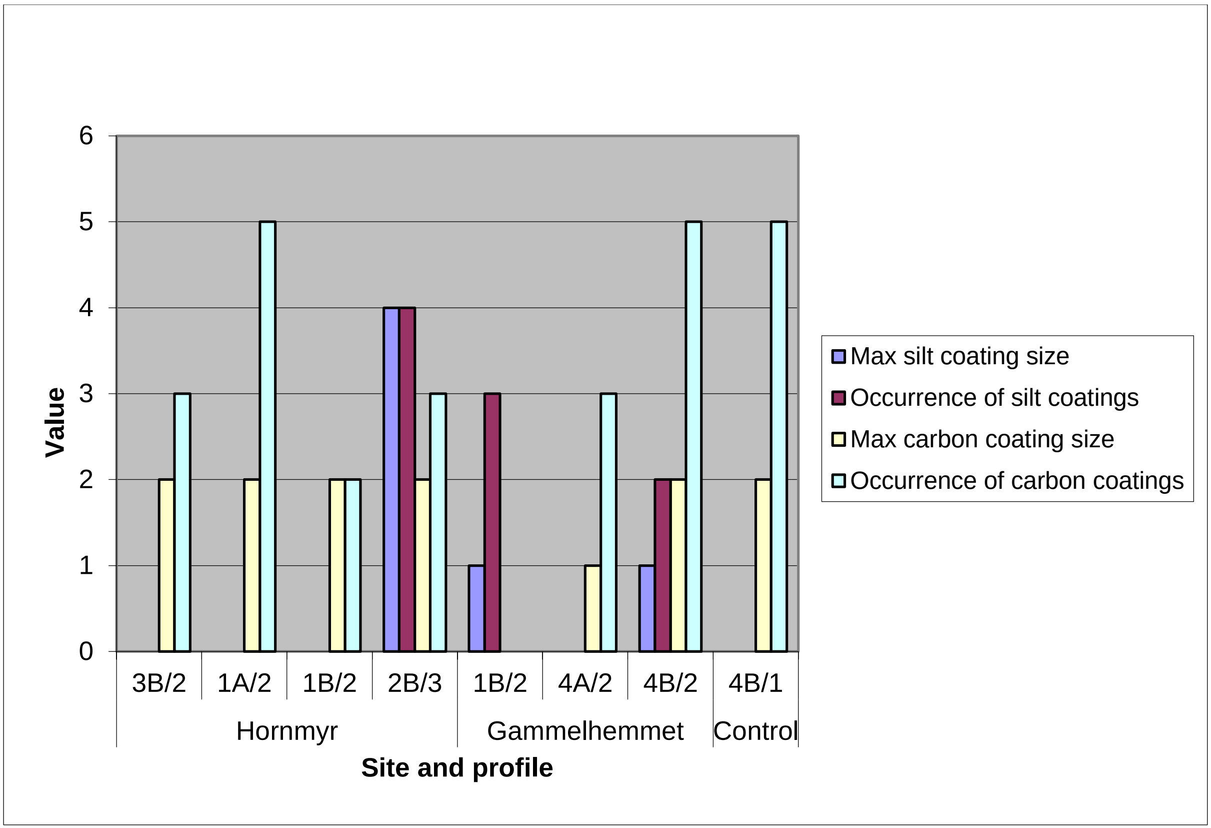


Figure 5.86: Graph showing maximum size & occurrence of silt and carbon coatings in the E-horizons of the European sites

The carbon coating size remains at level 2 or below and although the occurrence rate reaches level 5 at profile 1, site 5 and profile 4, site 6, it also reaches level 5 in the control sample and can therefore be related to the natural inclusions of charcoal and subsequent carbon from the forest fires.

Table 5.9 illustrates the averages for the E-horizon where although the average European silt coating size and occurrence is far higher than the control values (no silt capping's in control samples), the carbon coating size and occurrence are actually lower. This could be related to increased eluviation and illuviation activity within the traditional podzols compared to the altered European soils.

Table 5.9: Averages of maximum size & occurrence of silt and carbon coatings in the E-horizons of the European sites and their subsequent control samples; averages are of the size and occurrence levels as per the key table (5.7)

	Max silt coating size	Occurrence of silt coatings	Max carbon coating size	Occurrence of carbon coatings
Average European:	0.9	1.3	1.6	3.0
Average control:	0.0	0.0	2.0	5.0

Figure 5.87 shows the silt and carbon coatings, size and occurrence, for all B-horizons where silt capping's are present with the control samples for the first time. The average silt capping size is still larger than the control, see table 5.10, but has a similar occurrence level. The carbon coating size and occurrence are much closer and indicates that the difference seen in the A-horizon is related to the anthropogenic enhancement of the European profiles, and that this enhancement has not significantly altered the natural podzolisation processes enough to have any significant difference in the size and occurrence of the organic carbon coatings within the E and B horizons and indicates that charred material, other carbon rich material and/or carbon rich E-horizon material have been applied to the anthropogenic topsoil in order for it to have a higher size and occurrence rate of organic carbon coatings in the A-horizon.

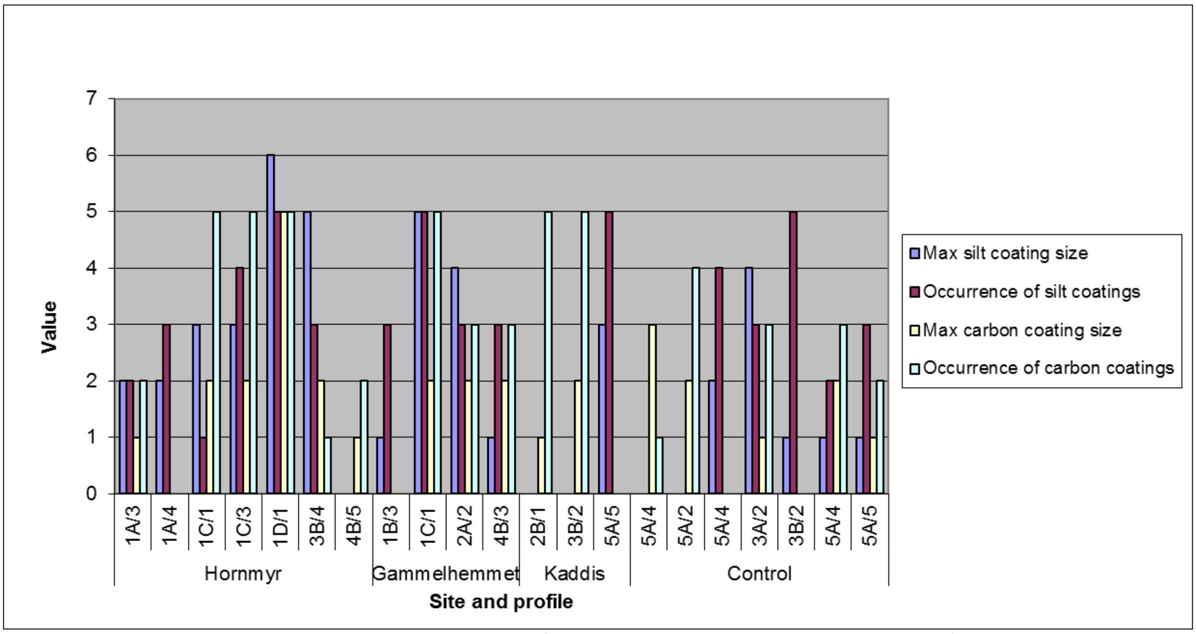


Figure 5.87: Graph showing maximum size & occurrence of silt and carbon coatings in the B-horizons of the European sites

Table 5.10: Averages of maximum size & occurrence of silt and carbon coatings in the B-horizons of the European sites and their subsequent control samples; averages are of the size and occurrence levels as per the key table (5.7)

	Max silt coating size	Occurrence of silt coatings	Max carbon coating size	Occurrence of carbon coatings
Average European:	2.6	2.6	1.6	2.9
Average control:	1.3	2.4	1.3	1.9

The averages of the silt and carbon coating sizes and occurrence rates in the A, E and B horizons for both the European site has been calculated in figure 5.88 and shows that as discussed, the silt capping size and occurrence goes against the typical trend of decreasing size and frequency with decreasing depth with silt capping's first appearing in the B-horizon of the control samples; the increase in size and occurrence in the anthropogenic A-horizon is due to the input of deeply sourced mineral material from elsewhere on the site, however the carbon coating size and level of occurrence remain similar throughout showing a very slight decrease in both size and frequency with decreasing horizon type.

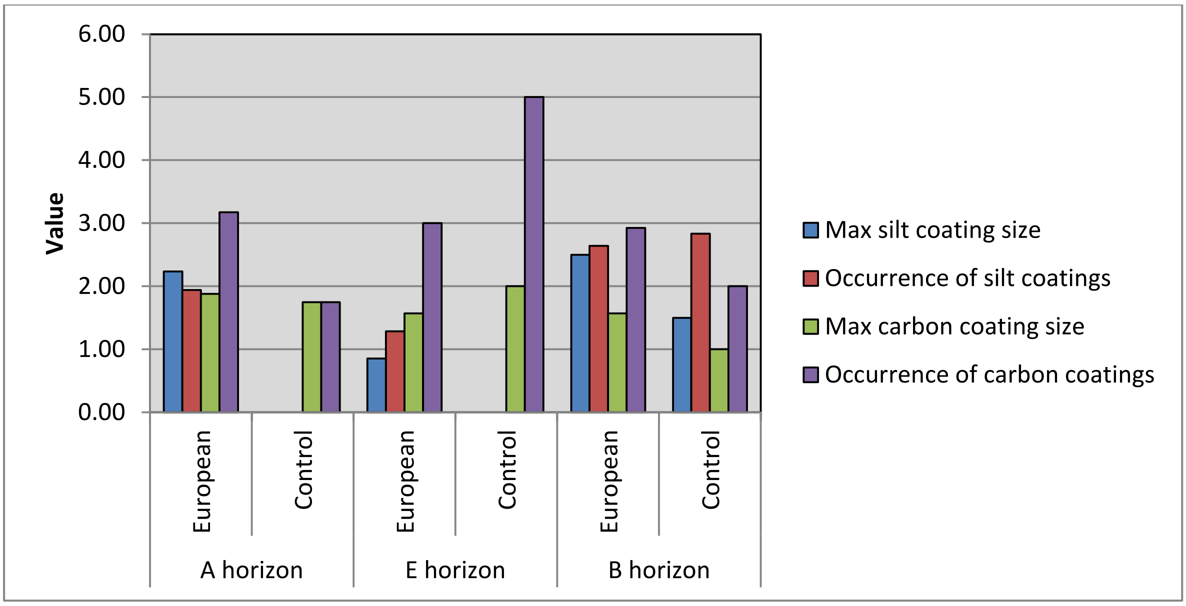


Figure 5.88: Bar graph showing the European and control averages for the maximum size and occurrence of silt and carbon coatings in the A, E and B horizons

5.5.3 Chemical analysis

The pH values show for the European sites contradict the pattern seen in the Sámi samples in that the pH does not always increase with depth; it does with the control samples taken at Gammelhemmet, profile 3 and at Kåddis, profile 4. This indicates that the amendment of the topsoil to an anthropogenic cultural soil significantly increases the acidity of the topsoil and in the case of profile 1 at Gammelhemmet can lead to a scenario where the pH actually decrease, even marginally, with depth; see figure 5.89 for a graph showing each value by horizon type. The average pH values of the E-horizons are slightly higher when underlying the anthropogenic soils at European sites when compared to the undisturbed Sámi sites (4.93 vs. 3.89 respectively) but the B-horizons are similar (4.83 vs. 4.56 respectively) indicating that the amendment of the A-horizon into a cultural 'plaggen' type soil has a positive effect on any underlying E-horizons but that the affect does not reach as far down as the B-horizon.

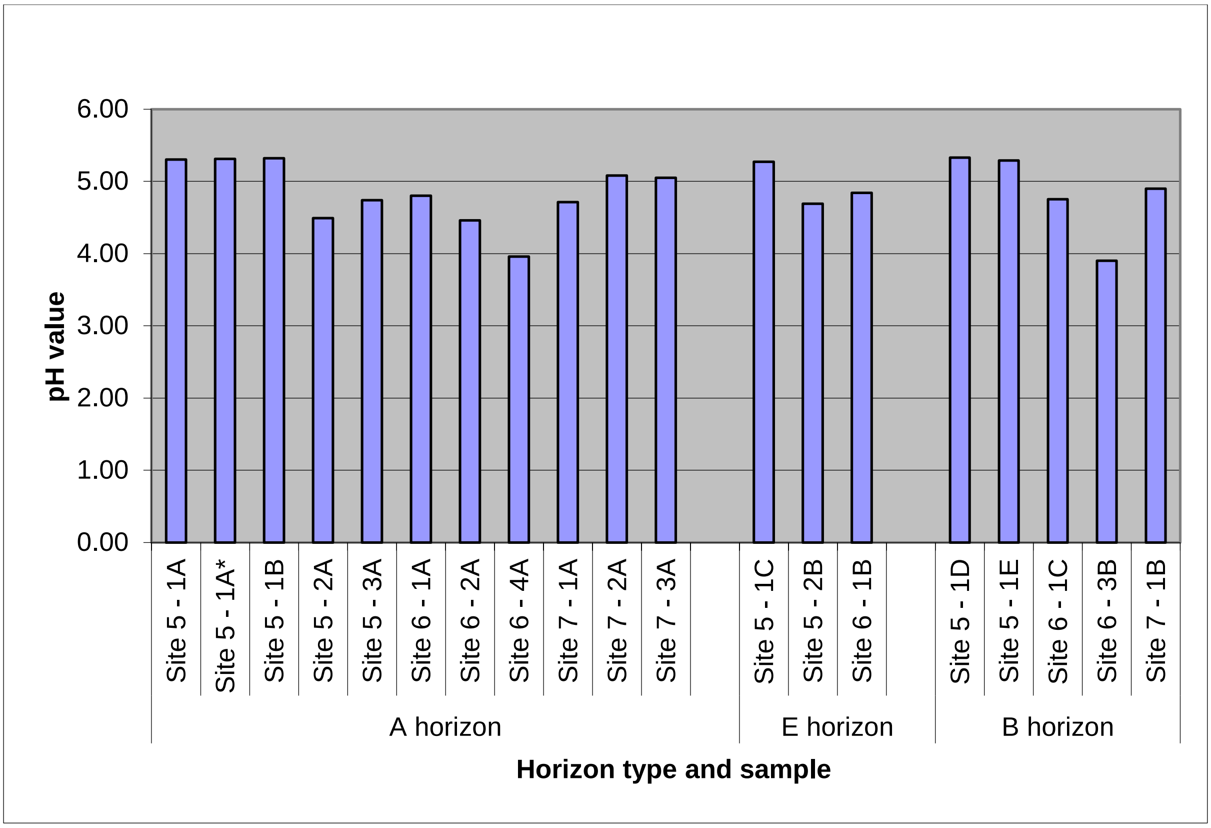


Figure 5.89: Bar graph showing the pH values for all profiles at Hornmyr, Gammelhemmet and Kåddis, sorted by horizon type

The average elemental concentrations have been graphed for the A, O, E and B horizons in figure 5.90 to look for patterns in deposition related to alluvial and eluvial processes associated with podzolisation. The higher concentration of elements in the A and B-horizons seen in the undisturbed Sámi profiles is visible here but the distinction seen between the E and B horizons is much less with the E-horizon being elementally richer than in the straight podzol soils at the Sámi sites. This can be related to the disturbed and often mixed nature of the E-horizons as well as the input of materials into the A-horizon which will have migrated down into the E-horizon. The differences between the anthropogenically enhanced A-horizon and natural O-horizon is apparent with a marked increase in phosphorous, potassium, calcium, titanium, chlorides and most markedly, in aluminium. The substantial increase in these anthropogenically associated elements fits well with the statistical outputs and marks a clear chemical signature for European activity within the A-horizon as well as secondary accumulations in any underlying E-horizons.

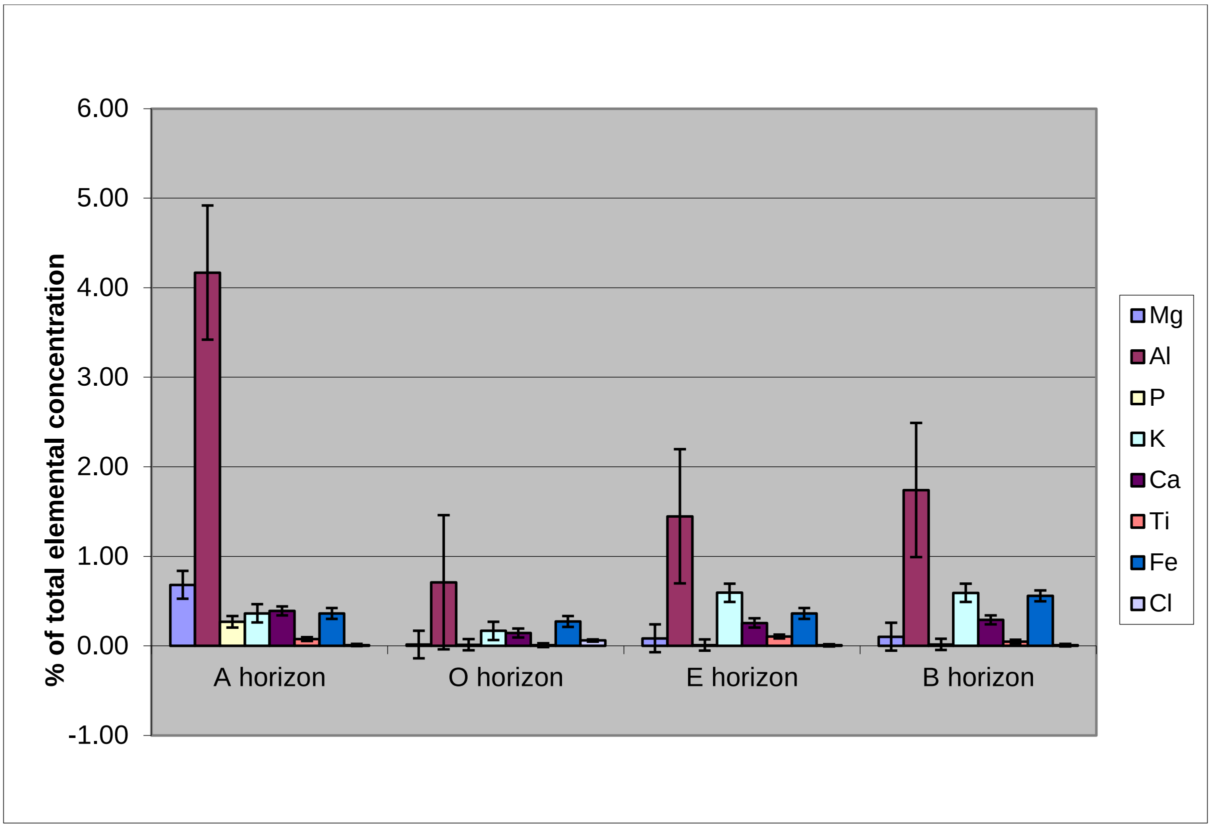


Figure 5.90: The average % elemental concentration of the A, O, E and B horizons calculated from all European sites; error bars set to 1 standard deviation

The aluminium and iron levels recorded at each micro-stratum from the top the bottom of each profile at Gammelhemmet has been graphed in figure 5.91 to illustrate the pattern of accumulation associated with podzolic soils further. Gammelhemmet has been chosen for this due to it beginning to repodzolise post abandonment to see if the elemental distribution of iron and aluminium associated with podzols is visible within the newly formed secondary E-horizon at profile 4 and if any other profiles have chemically began to form secondary E-horizons even though they are not visible yet.

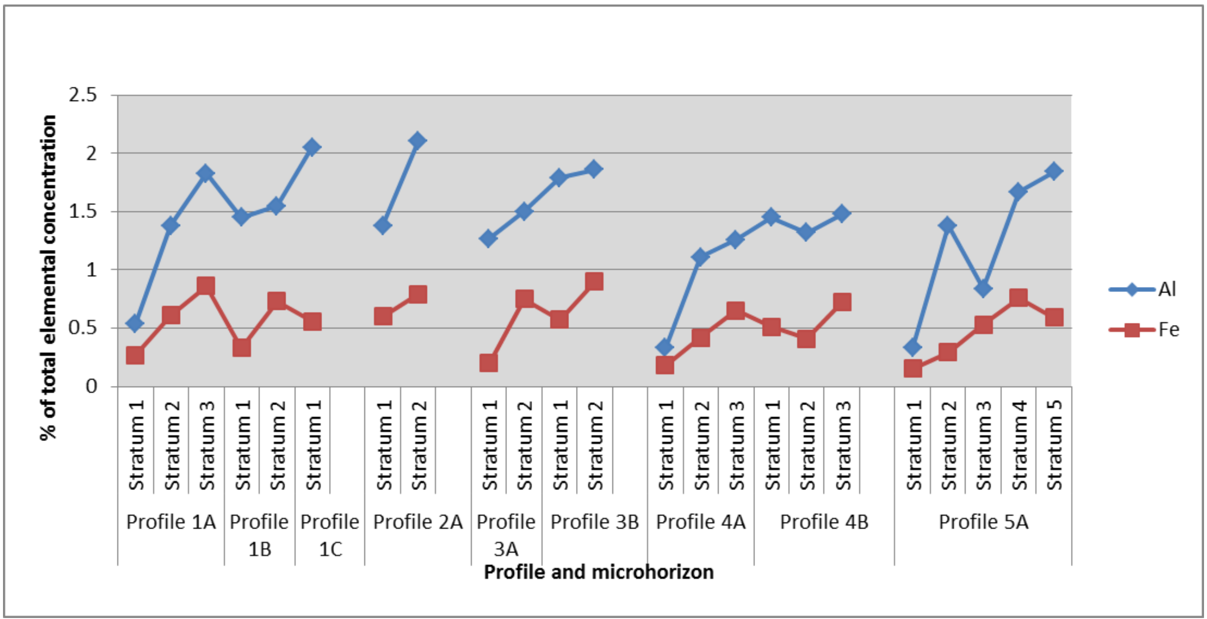


Figure 5.91: The aluminium and iron levels for each micro-strata (from top to bottom of profile) at Gammelhemmet

The distribution of iron and aluminium in the undisturbed podzol soils at the Sami and control locations showed occasional peaks within the A/O horizon, very low concentrations in the E-horizon before peaking in the B-horizon. Profiles 1, 2 and 4 at Gammelhemmet have had the topsoil's anthropogenically enhanced through cultivation and the addition of 'plaggen' type materials with profile 4 showing signs of a secondary E-horizon forming in the upper anthropogenic A-horizon; in micro-stratum 2 (MS2). Profile 4 exhibits a low Al and Fe concentration in the upper micro-stratum and an increased level in the second MS which has been identified as the secondary E-horizon and initially suggests that the E-horizon formation is still too early to have affected the soil chemistry however this micro-stratum is lower in both Al and Fe than the following, secondary B-horizon or than in the unaffected anthropogenic soil at MS 4. The Fe level falls again in the lower anthropogenic A-horizon in MH4 before both the Fe and Al concentrations fall in the primary E-horizon at MS5 and then peak in the original B-horizon at MS 6 as expected. This indicates that although only the secondary E-horizon is clearly visible in the thin section slides that the secondary A, E and B horizons are evident within the soil chemistry.

This pattern is partially repeated in profile 1 where the Al and Fe concentrations increase from MS 1-3 (the anthropogenic MS's) indicating the initial reformation of a podzolic A-horizon at MS1, the reducing levels at the E-horizon (MS2) and peak at the B-horizon (MS3) before falling again at the original E-horizon and peaking in the B-horizon (MS's 4 and 5 respectively).

The general linear model used to determine the normality of the data revealed that the four groups of data, the mixed, Sámi, European and control samples, were statistically distinct from one another so one way analysis of variance tests were used in addition to Tukey's multiple comparison graphs in order to establish where those differences lay. A significant difference was identified in the phosphorous levels (see figure 5.92). Increased phosphorous is a well-known indicator of anthropogenic activity and can be attributed to the added 'plaggen' type materials and cultivation practises seen in the micromorphology (Simpson, 1997).

```
Source    DF      SS      MS     F      P
Set        3  0.2545  0.0848  5.87  0.001
Error    136  1.9662  0.0145
Total    139  2.2207

S = 0.1202   R-Sq = 11.46%   R-Sq(adj) = 9.51%
                           Individual 95% CIs For Mean Based on Pooled StDev
                            Pooled StDev for Phosphorous
Level      N    Mean   StDev     +---------+---------+---------+---------
Sámi      58  0.0297  0.0405               (----*----)
European  42  0.1171  0.2127                                (------*-----)
Control   28  0.0214  0.0240           (-------*------)
                                 +---------+---------+---------+---------
                              -0.060     0.000     0.060     0.120
```

Figure 5.92: Output from Tukey's multiple comparisons regarding the Phosphorous levels between the Sámi, European and control samples

The aluminium levels at the European sites were also significantly different to the control and Sámi samples, see figure 5.93. Aluminium is associated with acidic soils, such as Scandinavian podzols (van Hees *et al,* 2001), meaning that these peaks could be attributed to the mixing and disturbance of the original podzolic soils through the cultural amendment of the topsoil. However as there was no significant difference in the iron levels, see appendixes, this relationship is more complicated than the simple mixing and re-distribution of aluminium and iron. There has been long standing knowledge of the drawbacks of too much aluminium in crop growing soils, with high aluminium levels often acting as a limiting factor on crop growth (Delhaize and Ryan, 1995). As the ionic forms of aluminium found in acidic environment are toxic to plants (Zheng, 2010), the decreased acidity seen in the European soils should have been beneficial to the crops grown. However as the aluminium level is statistically higher than the control samples it indicates that even with an increased pH, the aluminium levels are enough to impede crop growth.

```
Source    DF      SS     MS     F      P
Set        3   62.72  20.91  9.40  0.000
Error    136  302.43   2.22
Total    139  365.15

S = 1.491   R-Sq = 17.18%   R-Sq(adj) = 15.35%

                               Individual 95% CIs For Mean Based on
                               Pooled StDev for Aluminium levels
Level      N   Mean  StDev  -----+---------+---------+---------+----
Sámi      58  0.913  0.715      (----*-----)
European  42  2.461  2.517                          (-----*------)
Control   28  1.161  0.505       (-------*-------)
                            -----+---------+---------+---------+----
                               0.70      1.40      2.10      2.80
```

Figure 5.93: Output from Tukey's multiple comparisons regarding the Aluminium levels between the Sámi, European and control samples

5.5.4 Magnetic susceptibility

The magnetic susceptibility of all bulk soil samples were taken in order to try and establish areas of burning so that it could be tied to the micromorphology results. The data for all sites has been graphed together in figure 5.76 where there are two instances of diamagnetic readings and a peak at profile 4, Hornmyr, which was a control sample taken below a clearance cairn and indicates an intensive burning period which is linked to the charcoal content of 5% in the upper micro-stratum of micromorphology slide 4A and point towards the use of burning as part of the clearance technique at the site as it occurs directly below a very large clearance cairn. The two diamagnetic readings are found at profile 6A at Hornmyr, which is a waterlogged peat, and from sample 4D at Kåddis which is the B-horizon underlying an example of tree-throw from the control sample.

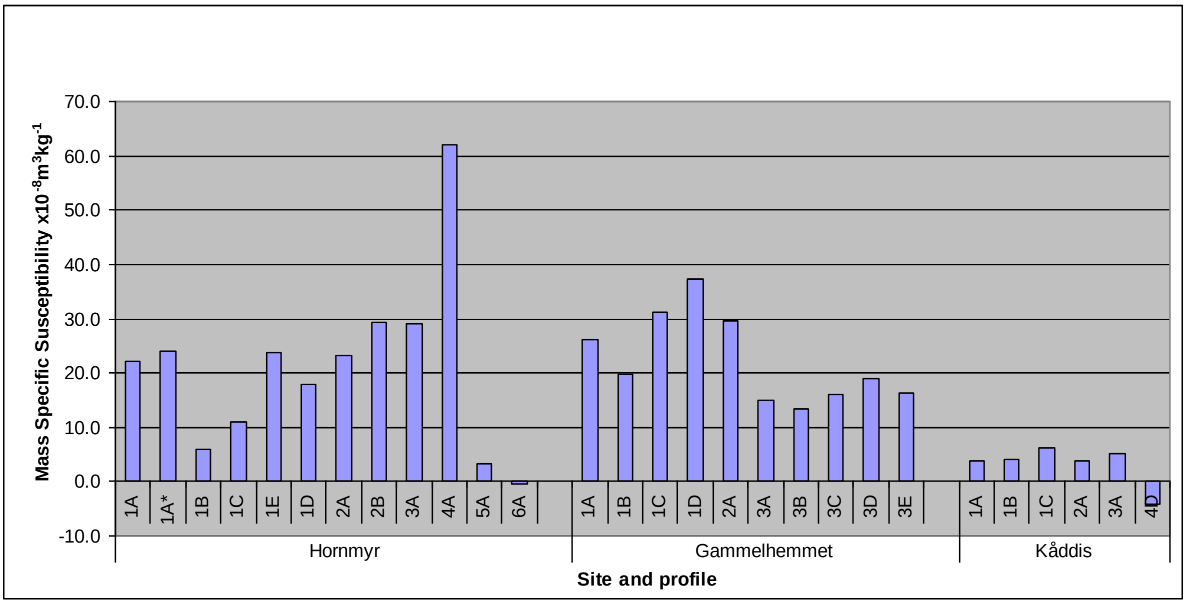


Figure 5.94: Magnetic susceptibility values for all profiles at Hornmyr, Gammelhemmet and Kåddis

The mass specific magnetic susceptibility was then graphed according to horizon type in figure 5.95 to try and establish what sort of relationship magnetic susceptibility had with the eluviation and illuviation processes at European sites. All in all there was great variation between sites and profiles, most likely due to varying levels of activity, with the lower values being seen at Hornmyr, so the average was calculated and graphed with the highest level being found in the A-horizon, closely followed by the B-horizon and then finally the E-horizon. As magnetic susceptibility is linked to burning events and as shown with the Sámi profiles fits well with the charcoal findings in the micromorphology it can be assumed that Hornmyr has had fewer and/or less intensive burning episodes that at Gammelhemmet and Kåddis but could also be linked to the age difference between the earlier settled Kåddis and the recently settled, and in Gammelhemmet case abandoned, sites in that the material has been mixed and worked over such a long period alongside the addition of material from elsewhere any magnetic signal has been subsequently diluted and due to the free draining nature of the underlying sands it's possible for the fine magnetic material to have migrated down profile beyond that sampled. The lower level seen in the E-horizon compared to the B-horizon fits with the podzolic nature of the site with materials moving down profile through the E-horizon and being deposited into the B-horizon.

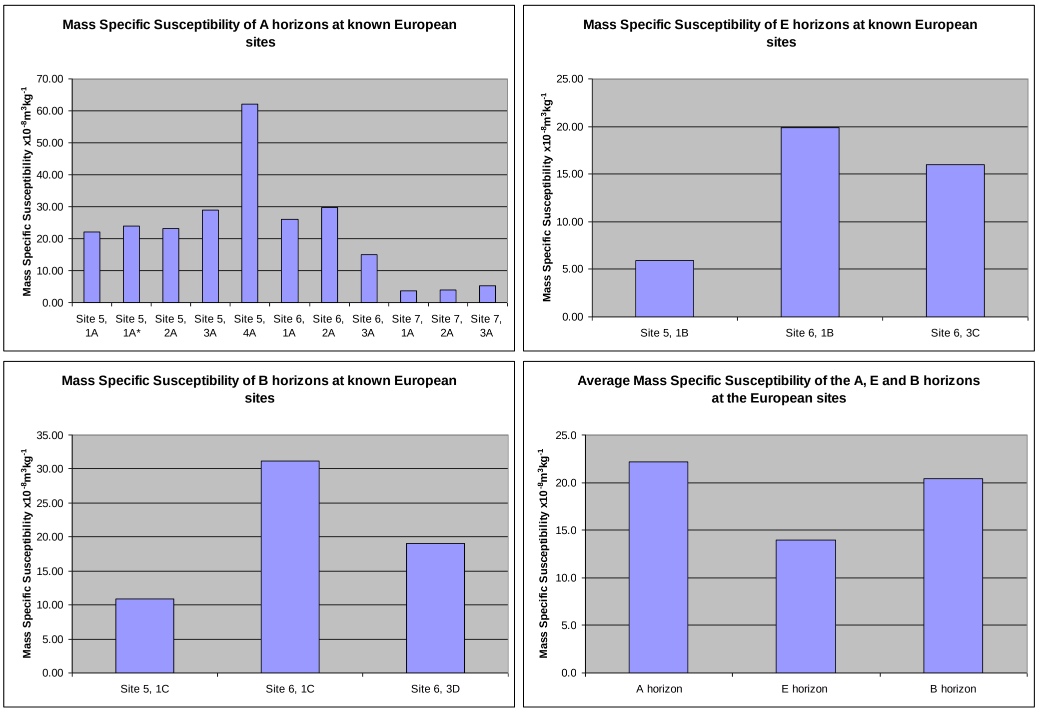


Figure 5.95: Magnetic susceptibility values for Hornmyr, Gammelhemmet and Kåddis sorted by horizon type plus a further graph showing the average magnetic susceptibility of the A, E & B horizons at the three European sites

5.6 The European soilscape

Cultural indicators have been discussed in associated with anthropogenic activity in chapter 1.1 with tables of cultural indicators associated with both Sámi and European activity being collated as well as secondary tables for cultural indicators associated with Sámi and European activities which will still be present in acidic podzol soils (see tables 1.1 and 1.2 in chapter 1.1). Now that the analysis of the thin section slides and bulk soil samples taken at known European sites has been completed the anticipated cultural indicators can be explored and confirmed and an updated table collated; this section will also act to outline the key findings from the European sites.

The homefield areas of the European sites show visual evidence of cultivation and in several instances also of turf turning (Hornmyr profile 1), ploughing (Gammelhemmet profile 4) and the formation of plaggen type topsoils through the addition of organic and mineral material (Hornmyr, Gammelhemmet and Kåddis) as anticipated in this area. Micromorphological and chemical analysis will be used to shed light on the management techniques used to form the anthropogenic topsoils which will include identifying which materials were 'added' to the soil. This will in turn identify which cultural indicators remain within acidic podzol based environments.

The field evidence displayed several visible cultural indictors which started with a visual change in vegetation cover from the heavily wooded (pine, spruce and birch) natural environment to an open grassland/arable field system.

The evidence of this change in land use was also visible through the altered soil profile which included unnaturally deep anthropogenic topsoil's, displaced and mixed soil horizons, the removal of large stones (seen in neighbouring clearance cairns) and the inclusion of cultural artefacts such as plough/ard marks as seen at profile 4, Gammelhemmet.

The micromorphological analysis of the European slides showed an input of plaggen type materials and mixing of soil strata associated with the central European management practices. There was no trace of bone, ash, shell or any other calcitic based materials in the anthropogenically enhanced topsoil's which has been accredited to the acidic nature of the underlying, original podzol soils so identification of anthropogenic soils has been based on the level of disturbance and mixing, changes to the microstructure and porosity, the input of organic materials, including turf, manure and charcoal, and the input of mineral material which has been sourced from E and B-horizons and the degree of homogenisation of the fine organo-mineral material. Although no traditional plough pans were visible, highly compacted and homogenised sub-strata are indicative of ploughing in this environment.

The turf material and any subsequent phytoliths and diatoms give indications of the environment where the turf material has originated from which in the case of Kåddis links nicely with the evolving environment and expanding resource collection areas. The silt per-glacial capping's on the mineral grains from the lower E and B horizons has proven to be a valuable resource for identifying the added mineral material in the anthropogenic horizons and offers, alongside the size of the mineral grains, a reliable indication of the not only the alien nature of the mineral grains at shallow depths but also the origin of the mineral material.

Charcoal strata are present at several of the control profiles surrounding the European sites with traces being evident within some of the anthropogenic topsoil's however there is also evidence to suggest that charring of the surface vegetation was also carried out by the settling Europeans as part of the clearance process so charcoal strata underlying, or partially mixed into, the anthropogenic topsoil at European sites in similar areas must have their origin diagnosed with care as although forest fires are common with the charred strata occurring frequently in the control and undisturbed Sámi profiles, the settlers may also have carried out their own burning event.

A key finding from the sites studied was that of the secondary E-horizon forming at the abandoned Gammelhemmet site. The return of the heavily worked cultural soil back to a podzol with a developing E-horizon and overlying organic accumulation confirms the acidic nature of the soil, the intensity of the on-going eluviation process and fits well with the podzol model created and discussed in the earlier soils section; see figure 5.96 for podzol model showing how the abandonment of a cultural soil can lead to the formation of a podzol soil.

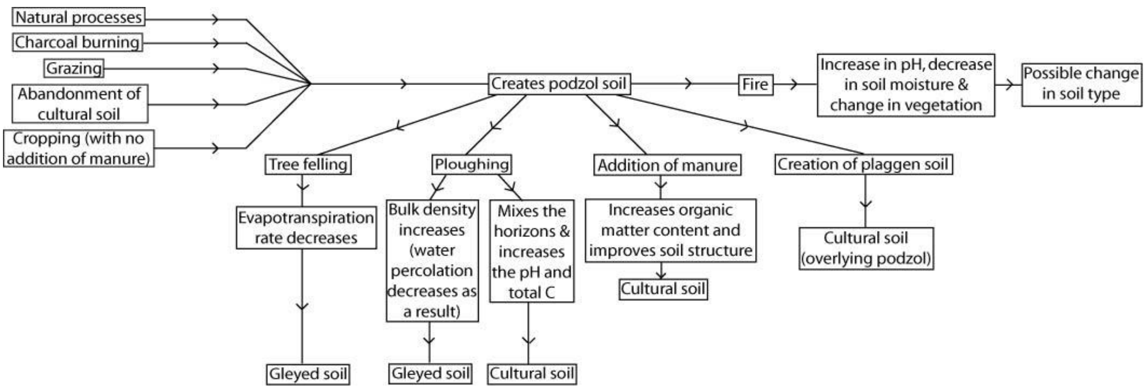


Figure 5.96: Podzol model showing the abandonment of cultural soil as one of the inputs leading to the formation of a podzol soil

The pH analysis showed that the pH value of the topsoil of Profile 4 at Gammelhemmet (which is re-podzolising) is the only anthropogenic topsoil to have a value less than 4 (pH value of 3.96). The pH values of the European profiles are typically higher in the A and E horizons in comparison to the undisturbed podzol soils at the Sámi sites, and control samples, but that the anthropogenic amendment had little effect on the B-horizon; see chapter 4.5.

The chemical element identification was carried out with the Scanning Electron Microscope on the thin section slides and confirmed, although to a slightly lesser degree than at the Sámi sites, the natural illuviation and eluviation podzolisation processes anticipated in the podzol based soils. The presence of a secondary E-horizon at profile 4 at Gammelhemmet, as seen in the micromorphology slides and by the low pH, is also visible in the extremely low iron and aluminium levels as shown by the SEM analysis; the low Fe and Al levels also seen in the other anthropogenic topsoil's at Gammelhemmet.

The SEM analysis also revealed some statistically significant differences between the European sites and the control profiles as well as between sites. The phosphorous (P), aluminium (Al) and magnesium (Mg) levels at the European sites were all significantly different (to 95% probability) to the control samples. The higher P level is a well-established cultural indicator and can be linked to the input of manure and other plaggen type materials to the anthropogenic topsoil. High Al levels are a well-known problem associated with arable farming and are again a reliable indicator of European activity.

Interestingly the comparison of the three European sites to each other showed that Kåddis and Gammelhemmet, the oldest and abandoned sites, were most similar and were significantly different to Hornmyr in their Magnesium, Phosphorus and Aluminium levels with Kåddis having a significantly different titanium level to Hornmyr and Gammelhemmet. The main differences here are the same as those highlighted by the comparison between the European, Sámi and control samples and indicates that although generally speaking the Mg, Al and P levels are markedly different at the European sites, they vary greatly from site to site and indicates that since the geology and vegetation is similar across the sites that the management techniques must vary. The difference in titanium levels between Kåddis and Hornmyr/Gammelhemmet could be linked to soil erosion and/or tree felling, especially when linked to the *Plantago* seed identified at Hornmyr (Görres and Frenzel, 1997; Hölzer and Hölzer, 1998). Overall heightened phosphorus and aluminium levels are reliable indicators of anthropogenically worked soils at European sites in northern Sweden.

The magnetic susceptibility of the soils varied greatly across each site. Due to the mixed nature of the anthropogenic horizon clear relationships between past burning episodes and the magnetic susceptibility are not visible and due to the high level of natural forest fires any peaks cannot automatically be linked to anthropogenic activity. Any peaks from samples in a naturally forest fire prone area would have to be carefully studied alongside supporting evidence in order to disentangle whether the peak was related to natural events of anthropogenic activity however due to the level of mixing and homogenisation seen at the European sites studied this would be extremely time consuming and most likely unfeasible.

Table 5.11 contains the ‘anticipated’ indicators we expected to find in acidic podzol soils at known European sites on the first row, and updated indicators from the analysis of bulk soil and thin section samples collected at known European sites in Northern Sweden on the second row. Several of the cultural indicators which were identified as possibly occurring, have been confirmed at the European sites studied. The table has simple yes or no data rather than levels of disturbance, percentages present etc. so must be used alongside in-depth analysis when trying to establish the source of disturbance at a site of unknown occupation; the results from the study sites in this thesis can be used as comparative data.

Even with the marked changes that European cultivation has had on the landscape the natural podzolic processes are always working, all be it at a reduced rate, in the background and can quickly take over if a cultural soil has been abandoned, i.e. Gammelhemmet, and could therefore also take over if the soil was not carefully managed. This, in addition to the increased aluminium levels, extremely fast rates of soil accumulation and poor climatic conditions, indicate an unstable and inhospitable environment, which needs to be carefully managed in order to produce the highest yield possible (and needed) without inadvertently damaging or reverting the soil back to its natural state.

The few cultural indicators, which are not fully destroyed by the acidic environment will most likely have been displaced within the profile due to the on-going eluviation and illuviation processes and makes the micromorphological analysis of past land management techniques challenging; however, the overall European impact is still clearly visible within the natural Sámi landscape. This means that past European settlements, even if abandoned can clearly be identified within this region due to the marked changes in soil depth, chemistry and structure even without the inclusion of typical cultural indicators such as bone, ash and fungal spores.

Overall, the settlement of Europeans on the past Sámi landscape has resulted in a marked change in the environment from localised changes in the soil profile to changes in the landscape through differences in vegetation cover.

Table 5.11: Table detailing cultural indicators associated with European occupation estimated in chapter 1 and those confirmed by analysis of bulk soil and thin sections collected at known European sites in northern Sweden

Visual			Micromorphological										Chemical		Added		
	Ploughmarks	Disturbed horizons	Bone	Charcoal	Burnt material	Ash	Type 113 fungal spores	Mite excrement	Coprolites	Phytoliths	Coatings & infillings	Microstructure	Increased P	Magnetic susceptibility	Increased Al	Elevated Ti	Seed
Anticipated	✔	✔	×	✔	✔	×	✔	✔	×	×	?	✔	✔	✔	N/A	N/A	N/A
Confirmed	*	✔	×	**	×	×	×	×	***	✔	****	✔	✔	×	✔	?	✔

*Ploughmarks can be identified by a highly homogenised and compacted microstructure
**Charcoal *may* be used as an indicator of European activity but will be extremely difficult to disentangle from natural charcoal
***Coprolites in the form of manure can be used as an indicator but are difficult to identify due to the level of biological activity and quick decomposition of organic material
****Coatings and infillings only indicative of European cultural activity if dislocated i.e. coatings associated with B-horizon present in anthropogenic topsoil and not in control topsoil. Organic carbon coatings are not associated with anthropogenic activity due to the high frequency of forest fires pre-settlement

Key:

✔	Yes
×	No
?	Unknown

Chapter 6: Discussion

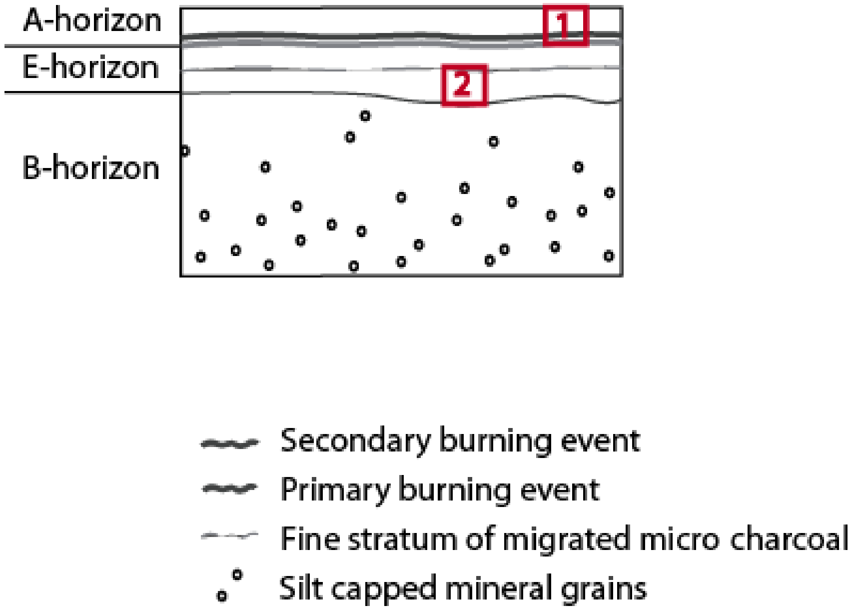
6.1 Sami and European soilscapes

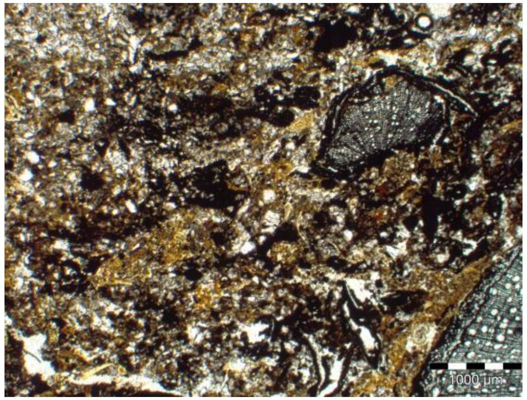
6.1.1 Introduction

The Sámi and European landscapes have been considered and analysed in the earlier chapters, with the Sámi soilscape being identified as showing almost no impact, and the European soilscape showing notable agriculture based impact. However there is still going to be an element of overlap between the indigenous Sámi population and the incoming European settlers, whether intended or not, resulting in a complex landscape of unapparent overlap where the European settler's footprint has been superimposed onto the 'natural' Sámi landscape (please refer to figures 1.1, 1.2 and 1.3 in chapter 1 for a generalised diagram of the European settlements within the Sámi region). In order to identify any interaction, the cultural indictors identified for each cultural group in the corresponding landscape chapters will be integrated and contrasted so that any overlapping qualities can be identified, and therefore used to detect interaction.

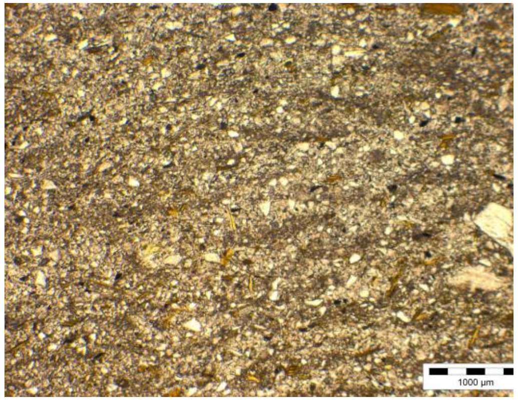
6.1.2 Field evidence

The field evidence for the Sámi sites is in stark contrast to those at the European sites which is predominantly due to the difference in on-site activities. The current vegetation cover will not necessarily be the same as when the sites were occupied and/or settled but shows differences between the sites. The wooded vegetation cover seen at the Sámi sites, mixed pine and birch woodland, has been cleared away and opened up at the European sites. This removal of cover vegetation fits with the preparation activities for agricultural use of the land (Kristiansen, 2000). The agricultural nature of the Europeans land use is also responsible for the difference in the upper soil horizons when compared to the Sámi sites. The cultivated soils at the European sites typically have deep anthropogenic topsoil's which overly a preserved, although sometimes disrupted, podzol. The preserved podzol is the remainder of the past Sámi landscape and demonstrates the marked impact that this style of European land management has had on the previously unaffected podzol based landscape, intrinsic of Sámi occupation and land use as mentioned at the end of the Sámi landscape chapter; as no clear indicators of Sámi occupation were identified in the Sámi landscape chapter it cannot be said whether or not the Sámi directly occupied the European sites studied, before they were indeed settled by the Europeans, however it does signify that the pre-European landscape was a natural mixed pine forest overlying podzol soils with no lingering anthropogenic footprint. To highlight the difference in the 'typical' soil profiles at the Sámi and European sites schematic profile drawings of each are shown in figures 6.1 and 6.2; presented respectively.



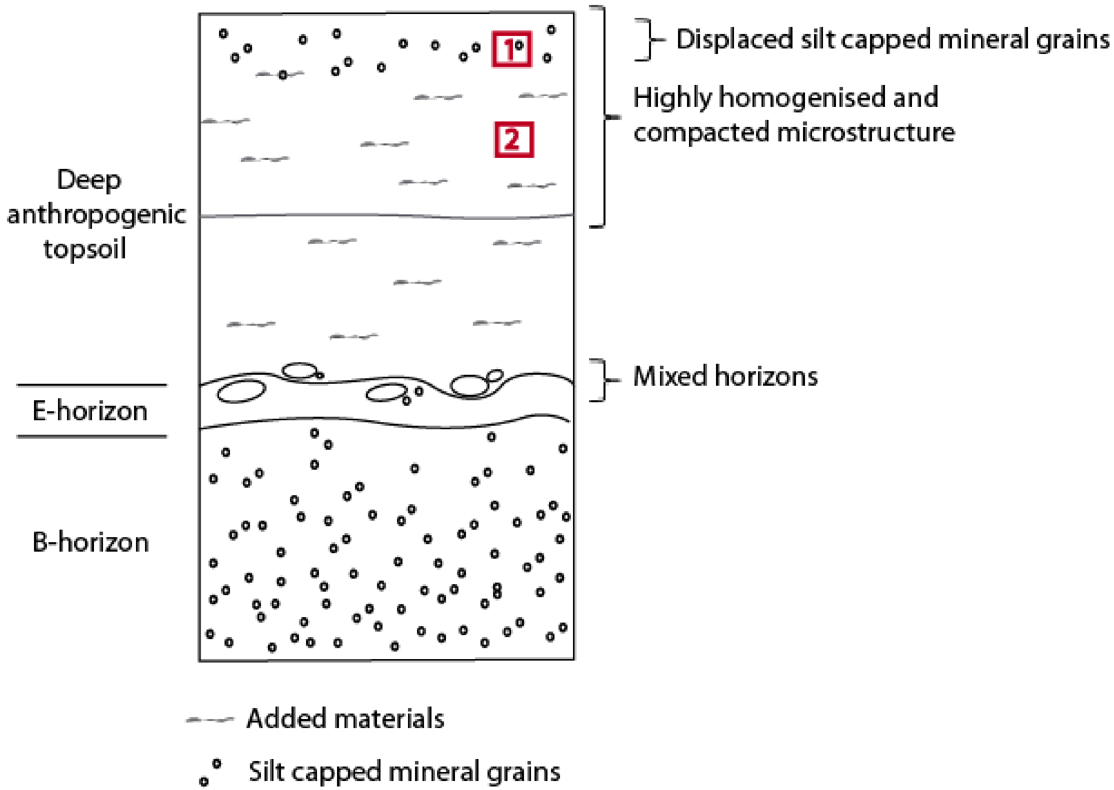


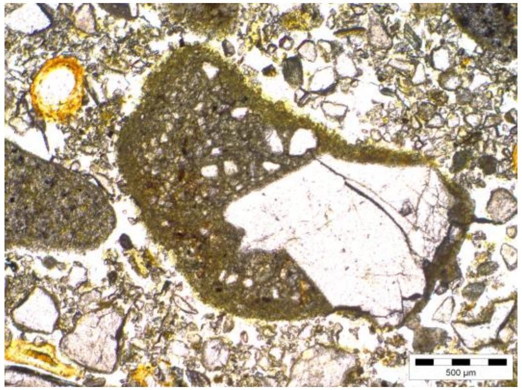
Photograph 1: Biologically active organic accumulation overlying charred stratum



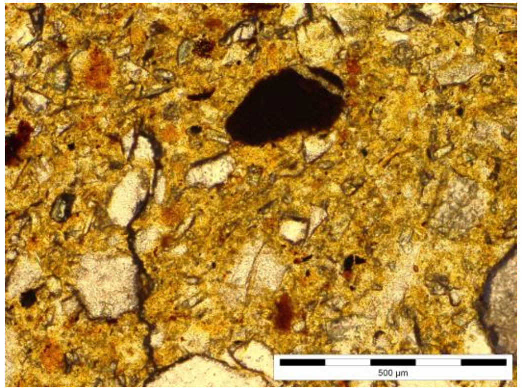
Photograph 2: Lenticular microstructure of the albic horizon

Figure 6.1: 'Typical' podzol profile expected to be found at Sámi site





Photograph 1: Displaced, silt coated mineral grain; originated in lower (E/B) horizon



Photograph 2: Highly homogenised /compacted microstructure; contains turf

Figure 6.2: 'Typical' amended podzol profile expected to be found at European site

6.1.3 Chronology

The chronology of the sites indicates four phases; phases identified by coloured overlay (see figure 6.3 for the radiocarbon graph). The earliest phase is seen exclusively at Tjärdal (marked by green) and is extremely early when considering the study period; the early date is most likely due to the shallow depth of the soil, resulting in historic samples near to the surface. The second phase is seen across all three of the Sámi sites as well as at Hornmyr. The third phase is only present within the Sámi sites but the fourth and final phase (yellow) occurs at the Sámi sites of Lass Mass Heden and Tjärdal, and across all European sites.

Phasing exclusively within the study period cannot be reliably identified as the individual dates have a large spread, however overall the burning events have occurred in phases and due to the high frequency of forest fires within the area, and their easily spread nature, they have been deemed as being natural and connected; the difference in the phases between the Sámi and European sites may be related to the shallower nature of the Sámi soils and the number and location of the samples chosen for dating. The picture does however indicate an increase in forest fire activity over time, something which may or may not be related to increasing population numbers and the influx of European settlers to first the coastal areas and later, inland.

Comparisons between the dates returned here and the dates established at Prästsjödiket by Västerbotten Museum show that the earlier grave and cooking pits at identified fall between the green and red phases seen here (grave dated to BC 1590 and pits dated to BC 800, 700 and 400) and the later dated cooking pits sit between the red and blue phases; AD 500, 700 and 800 (Andersson, 2000). This is further evidence that the material dated by Västerbotten museum is anthropogenic in origin as it does not fit with the emerging phases identified here.

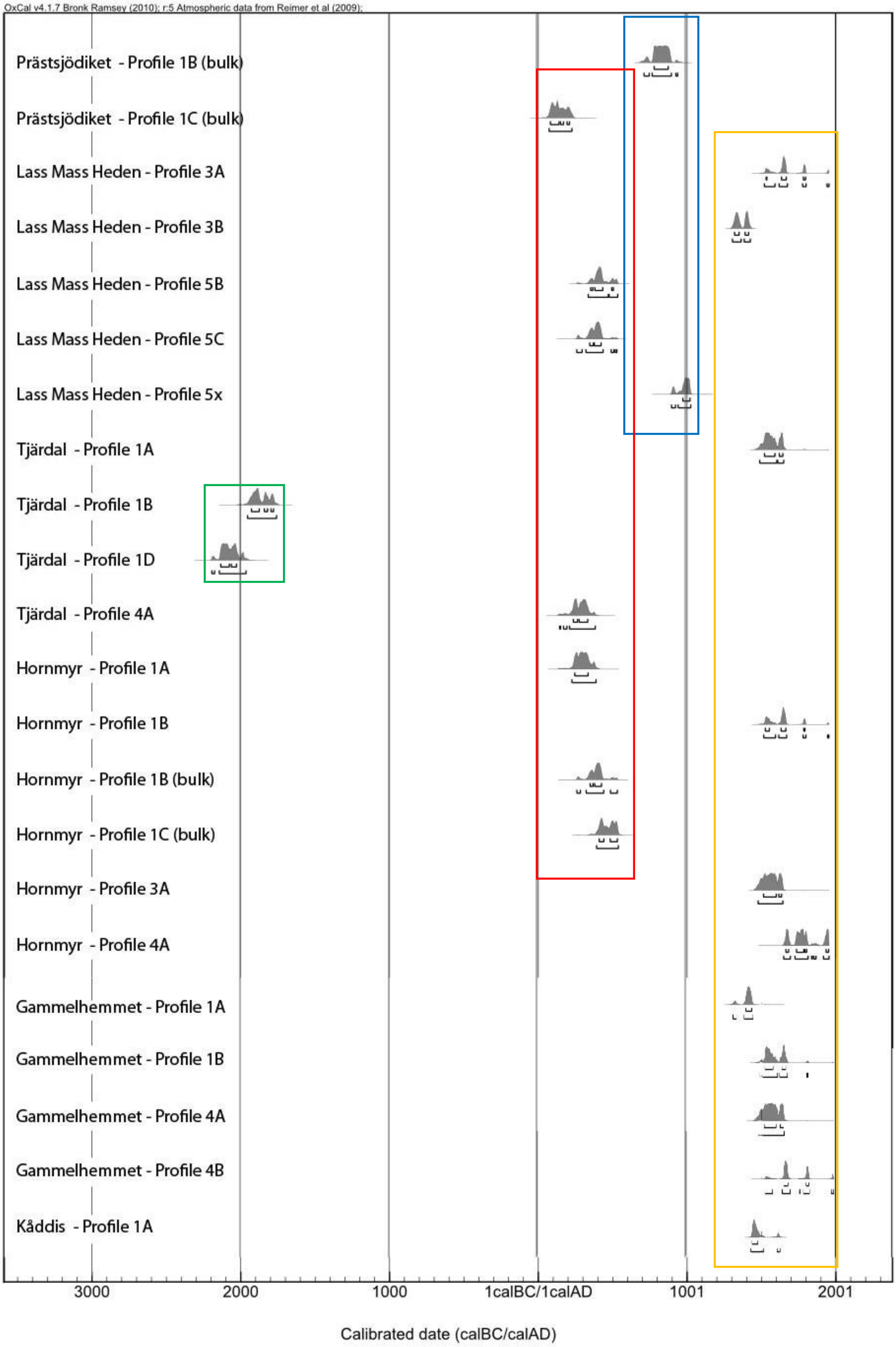


Figure 6.3: Radiocarbon plots showing calibrated dates for the material dated from both the European and Sámi sites

6.1.4 Micromorphology and coatings

The micromorphological analysis reflects the difference in on-site activities as discussed in the field evidence section; with the Sámi slides returning evidence of reindeer husbandry and the European slides returning agriculture based indicators. Some key findings of this study are related to the cultural indicators at the European sites; due to the acidic nature of the underlying podzol soils and on-going podzolic processes several of the anticipated cultural indicators were not present and those that were had been subjected to a range of factors making interpretation difficult.

The micromorphological differences between the Sámi and European landscape included, for the upper horizons, the change in microstructure from lenticular to granular, increased compaction, loss of structure (homogenisation) of fine material, the disruption and mixing of the organic horizon, the addition of several plaggen type materials from turf fragments to mineral material and an increase in mineral grain size and coatings (see figure 6.4 for a bar graph showing the increased level in the silt capping size & occurrence within the anthropogenic topsoil at the European sites compared to the A-horizon of the Sámi sites). A further graph has been constructed giving the average size and occurrence of the silt and carbon coatings within the anthropogenic topsoil/A-horizon, B-horizon and C-horizon for the European, Sámi and control samples (see figure 6.5). This visually shows that the silt capping's present throughout the anthropogenic profiles are alien to the corresponding natural and undisturbed Sámi soil horizons.

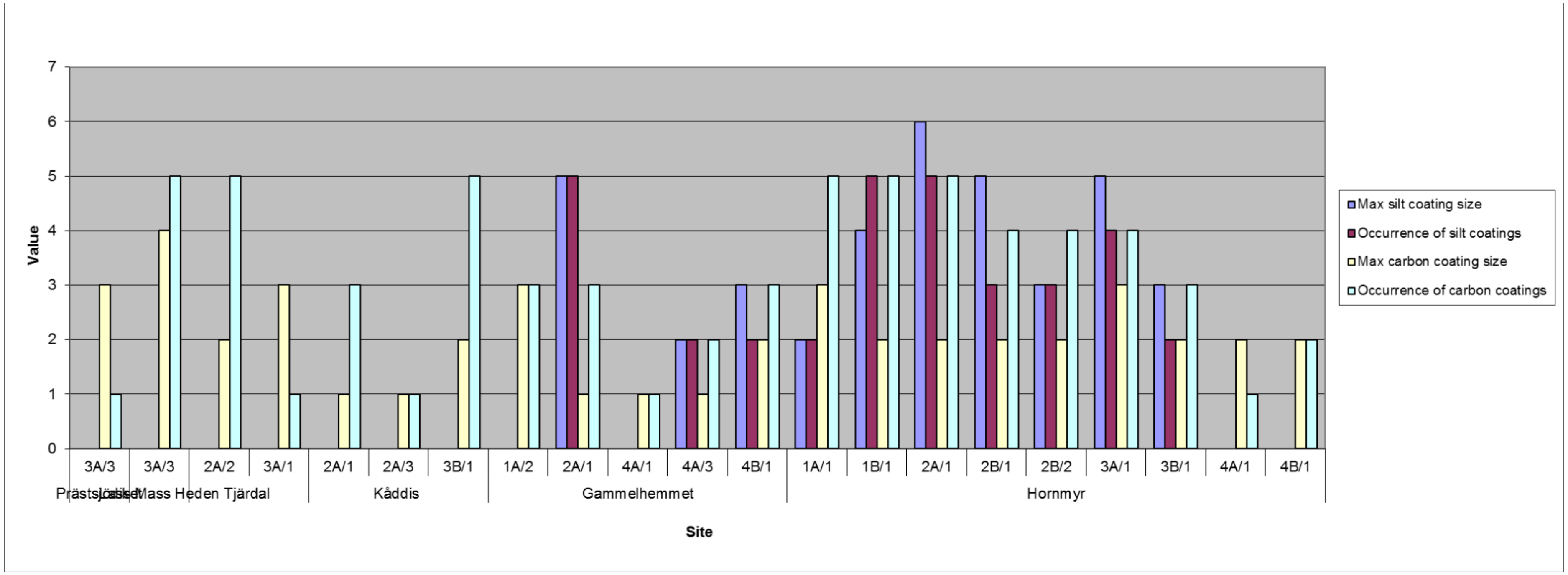


Figure 6.4: Bar graph showing maximum size & occurrence of silt and carbon coatings in the A horizons of the Sámi sites and anthropogenic topsoil's of the European sites; as measured in the thin section micromorphology slides

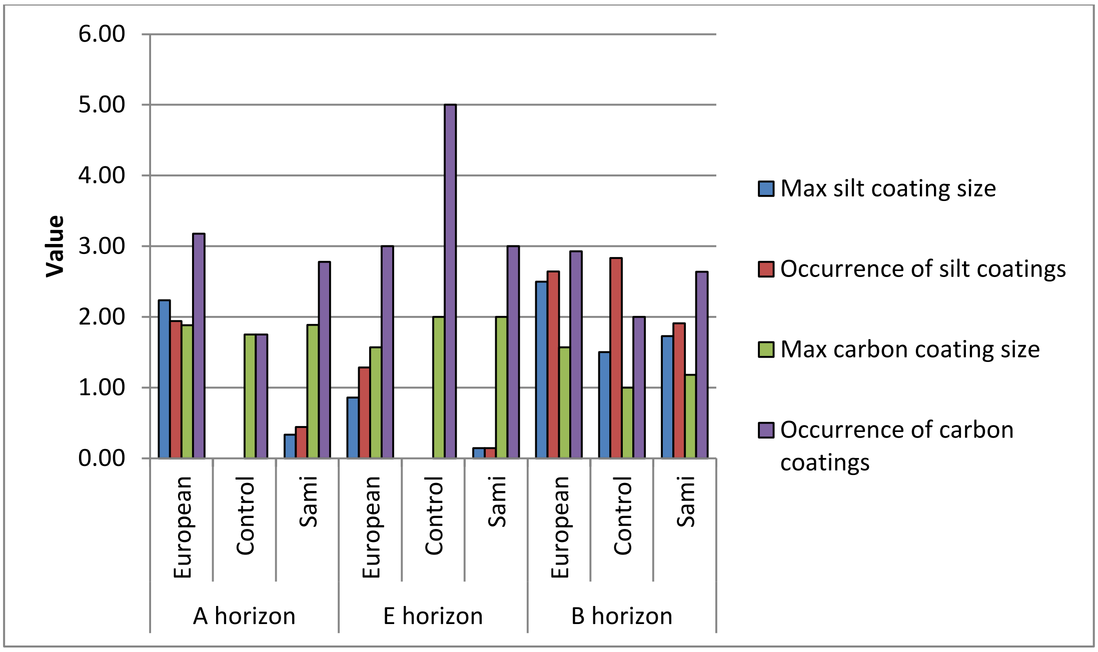


Figure 6.5: Bar graph showing the average size & occurrence of silt and carbon coatings in the A, E and B horizons for the European, Sámi and control samples; as measured in the thin section micromorphology slides

Interestingly the charcoal content and size within the European soils were much lower than those at the Sámi sites even though they theoretically would have started with the same amount of charcoal if they have been exposed to the same burning events, as identified by the burning phases in the radiocarbon graph in addition to any input of charred material as part of any land management technique. This has been attributed to the level of mixing within the anthropogenic soils which has led to the fragmentation of the charcoal which will have sped up its dissolvent and movement down profile; the addition of mineral material from elsewhere on site may also have had a diluting effect on the charcoal which will have added to the decreased percentage of charcoal present. On a different note the similarities between the two cultures supports the theory that anthropogenic topsoil's are still subject to podzolic processes; by the movement of fine material, both organic and in-organic, down profile. This is further supported by the discovery of a secondary albic horizon within the topsoil of the abandoned Gammelhemmet site.

6.1.5 Chemical analysis

Chemical analysis looking at differences within the site types, i.e. Sámi and European, were carried out in the corresponding landscape chapters. Consequently one way ANOVA's have been used here to establish if there are any differences between the two site types; both were tested against the control data.

The one way ANOVA's have been calculated with Tukey's multiple comparison graph so that statistically significant results could be determined via their p-value but that their relationships to the others factors could also be visible. The analysis was carried out across a suite of elements but only the statistically significant, or close to being significant, results are shown here; please refer to the appendixes for the full set of calculations. As with the comparisons in the Sámi and European Landscape chapters the significant range has been highlighted in yellow.

Figure 6.6 shows the multiple comparison results for the average Titanium level present in the Sámi, European and control samples. It is clear that the Sámi samples are statistically significant from the control samples but interestingly the European signal falls directly between the two. This indicates that the Titanium level may be an indicator of anthropogenic activity but that the Sámi have altered the Titanium levels in some way which has not been repeated by the European settlers. This would mean that significant changes in the Titanium levels could be a possible indicator of Sámi occupation.

```
Source    DF        SS        MS     F      P
Set        3   0.01858   0.00619  2.79  0.043
Error    136   0.30132   0.00222
Total    139   0.31990

S = 0.04707   R-Sq = 5.81%   R-Sq(adj) = 3.73%

                              Individual 95% CIs For Mean Based on
                              Pooled StDev for Titanium levels
Level     N     Mean    StDev  ---+---------+---------+---------+------
Sámi     58  0.04224  0.04949          (-----*-----)
European 42  0.05905  0.04477                 (-------*------)
Control  28  0.07071  0.04898                      (-------*--------)
                               ---+---------+---------+---------+------
                                0.020     0.040     0.060     0.080
```

Figure 6.6: Output from Tukey's multiple comparisons regarding the Titanium levels between the Sámi, European and control sites

Figure 6.7 shows the multiple comparison output for the chloride levels. Again we have a difference, although not statistically significant, between the Sámi and control samples with the European trace falling closer to the control sample. This, like with the Titanium levels, could be an indicator of Sámi activity.

```
Source    DF        SS        MS     F      P
Set        3   0.02264   0.00755  5.04  0.002
Error    136   0.20358   0.00150
Total    139   0.22621

S = 0.03869   R-Sq = 10.01%   R-Sq(adj) = 8.02%

                              Individual 95% CIs For Mean Based on
                              Pooled StDev for Chloride levels
Level     N     Mean    StDev  --+---------+---------+---------+-------
Sámi     58  0.04810  0.04685                          (-----*-----)
European 42  0.02024  0.02858         (-------*------)
Control  28  0.02964  0.03825             (---------*--------)
                               --+---------+---------+---------+-------
                               0.000     0.016     0.032     0.048
```

Figure 6.7: Output from Tukey's multiple comparisons regarding the Chloride levels between the Sámi, European and control sites

Whereas the Potassium comparisons showed a similarity between the European and Control samples but a skew to the Sámi results indicating that Sámi activity may have a mild effect on Potassium levels; see figure 6.8.

```
Source    DF       SS       MS     F      P
Set        3   0.2545   0.0848  5.87  0.001
Error    136   1.9662   0.0145
Total    139   2.2207

S = 0.1202   R-Sq = 11.46%   R-Sq(adj) = 9.51%

                            Individual 95% CIs For Mean Based on
                            Pooled StDev for Potassium
Level      N    Mean   StDev  -------+---------+---------+---------+--
Sámi      58  0.3016  0.2797  (------*------)
European  42  0.4093  0.2386            (-------*-------)
Control   28  0.3996  0.2291         (---------*---------)
                              -------+---------+---------+---------+--
                                  0.30      0.40      0.50      0.60
```

Figure 6.8: Output from Tukey's multiple comparisons regarding the Potassium levels between the Sámi, European and control samples

Figure 6.9 shows the multiple comparison output for the average Magnesium level. The European signal is statistically significant from both the control and Sámi signals showing that a statistically different Magnesium level can be an indicator of European activity. This is repeated with Phosphorous and Aluminium (see figures 6.10 and 6.11 respectively).

```
Source    DF       SS       MS     F      P
Set        3   1.8591   0.6197  7.08  0.000
Error    136  11.8974   0.0875
Total    139  13.7564

S = 0.2958   R-Sq = 13.51%   R-Sq(adj) = 11.61%

                            Individual 95% CIs For Mean Based on
                            Pooled StDev for Magnesium
Level      N    Mean   StDev  ------+---------+---------+---------+---
Sámi      58  0.0528  0.0792      (-----*------)
European  42  0.3160  0.5248                         (------*-------)
Control   28  0.0807  0.0674      (--------*--------)
                              ------+---------+---------+---------+---
                                 0.00      0.12      0.24      0.36
```

Figure 6.9: Output from Tukey's multiple comparisons regarding the Magnesium levels between the Sámi, European and control samples

The Sodium levels showed a similar output for the Sámi and control samples but a significant difference between the Sámi and European samples, suggesting that the different cultures both had an impact on the Sodium levels but in opposite ways (see figure 6.12).

```
Source    DF      SS      MS     F      P
Set        3  0.2545  0.0848  5.87  0.001
Error    136  1.9662  0.0145
Total    139  2.2207

S = 0.1202   R-Sq = 11.46%   R-Sq(adj) = 9.51%

                                 Individual 95% CIs For Mean Based on Pooled StDev
                                  Pooled StDev for Phosphorous
Level      N    Mean   StDev     +---------+---------+---------+---------
Sámi      58  0.0297  0.0405               (----*----)
European  42  0.1171  0.2127                                 (------*-----)
Control   28  0.0214  0.0240           (-------*------)
                                 +---------+---------+---------+---------
                              -0.060     0.000     0.060     0.120
```

Figure 6.10: Output from Tukey's multiple comparisons regarding the Phosphorous levels between the Sámi, European and control samples

```
Source    DF      SS     MS     F      P
Set        3   62.72  20.91  9.40  0.000
Error    136  302.43   2.22
Total    139  365.15

S = 1.491   R-Sq = 17.18%   R-Sq(adj) = 15.35%

                               Individual 95% CIs For Mean Based on
                               Pooled StDev for Aluminium levels
Level      N   Mean  StDev  -----+---------+---------+---------+----
Sámi      58  0.913  0.715     (----*-----)
European  42  2.461  2.517                        (-----*------)
Control   28  1.161  0.505      (-------*-------)
                            -----+---------+---------+---------+----
                               0.70      1.40      2.10      2.80
```

Figure 6.11: Output from Tukey's multiple comparisons regarding the Aluminium levels between the Sámi, European and control samples

```
Source    DF      SS      MS     F      P
Set        3  0.7691  0.2564  4.61  0.004
Error    136  7.5562  0.0556
Total    139  8.3253

S = 0.2357   R-Sq = 9.24%   R-Sq(adj) = 7.24%

                                 Individual 95% CIs For Mean Based on
                                 Pooled StDev for Sodium
Level      N    Mean   StDev  --------+---------+---------+---------+-
Sámi      58  0.2767  0.2567  (-----*-----)
European  42  0.4460  0.2087               (-------*------)
Control   28  0.3518  0.1956      (--------*--------)
                              --------+---------+---------+---------+-
                                    0.30      0.40      0.50      0.60
```

Figure 6.12: Output from Tukey's multiple comparisons regarding the Sodium levels between the Sámi, European and control samples

Due to the number of differences between the Sámi and European sites one way ANOVA's were carried out to compare the topsoil's at each of the seven sites. The difference between the anthropogenically enhanced topsoil's at the European sites and the thin A horizons at the Sámi sites is evident through the statistically significant differences in the sodium, magnesium, aluminium and calcium levels (see figures 6.13 to 6.16). Interestingly a statistically significant relationship is visible for the phosphorous levels at Gammelhemmet and Kåddis, compared to the Sámi sites, but the values for Hornmyr sits within the same range as the Sámi values (see figure 6.17). This could indicate a difference in input materials on site but as there is evidence of turf and organic inputs at Hornmyr the reduced phosphorous level is likely to be related to the intensive use of the site, again evident from the micromorphological analysis. This indicates that Hornmyr has been intensively cropped to the point that the inputted materials are not replacing some of the nutrients lost through cropping.

```
Source  DF      SS      MS     F      P
Site     6  1.0280  0.1713  7.65  0.000
Error   20  0.4478  0.0224
Total   26  1.4758

S = 0.1496   R-Sq = 69.66%   R-Sq(adj) = 60.56%

                                    Individual 95% CIs For Mean Based on
                                    Pooled StDev
Level             N    Mean   StDev  ------+---------+---------+---------+---
Prästsjödiket     2  0.0600  0.0849  (-------*--------)
Lass Mass Heden   3  0.0967  0.1422     (------*------)
Tjärdal           3  0.0300  0.0265  (------*------)
Hornmyr           9  0.4978  0.1919                        (---*---)
Gammelhemmet      6  0.3367  0.1347                (----*-----)
Kåddis            3  0.5700  0.0819                        (------*------)
                                   ------+---------+---------+---------+---
                                       0.00      0.25      0.50      0.75
Pooled StDev = 0.1496
```

Figure 6.13: Output from Tukey's multiple comparisons regarding the Sodium levels for all Sámi and European sites

```
Source  DF      SS     MS      F      P
Site     6   8.010  1.335  12.60  0.000
Error   20   2.119  0.106
Total   26  10.129

S = 0.3255   R-Sq = 79.08%   R-Sq(adj) = 72.81%

                                Individual 95% CIs For Mean Based on Pooled StDev
Level            N    Mean   StDev   +---------+---------+---------+---------
Prästsjödiket    2  0.0000  0.0000      (------*------)
Lass Mass Heden  3  0.0933  0.1617         (----*-----)
Tjärdal          3  0.0000  0.0000       (-----*-----)
Hornmyr          9  0.1189  0.0551           (---*--)
Gammelhemmet     6  0.9733  0.6205                       (---*---)
Kåddis           3  1.5733  0.2419                              (----*-----)
                                     +---------+---------+---------+---------
                                   -0.70      0.00      0.70      1.40

Pooled StDev = 0.3255
```

Figure 6.14: Output from Tukey's multiple comparisons regarding the Magnesium levels for all Sámi and European sites

```
Source  DF      SS     MS      F      P
Site     6  198.00  33.00  10.83  0.000
Error   20   60.94   3.05
Total   26  258.94

S = 1.746   R-Sq = 76.47%   R-Sq(adj) = 69.41%

                              Individual 95% CIs For Mean Based on
                              Pooled StDev
Level            N   Mean  StDev  ---------+---------+---------+---------+
Prästsjödiket    2  0.415  0.346    (------*-------)
Lass Mass Heden  3  0.623  0.778      (-----*-----)
Tjärdal       3  0.190  0.036    (-----*-----)
Hornmyr       9  1.554  0.473          (--*---)
Gammelhemmet  6  5.345  3.344                    (---*----)
Kåddis        3  8.380  0.979                           (-----*-----)
                               ---------+---------+---------+---------+
                                       0.0       3.5       7.0      10.5

Pooled StDev = 1.746
```

Figure 6.15: Output from Tukey's multiple comparisons regarding the Aluminium levels for all Sámi and European sites

```
Source  DF      SS      MS     F      P
Site     6  0.4911  0.0819  5.19  0.002
Error   20  0.3157  0.0158
Total   26  0.8069

S = 0.1256   R-Sq = 60.87%   R-Sq(adj) = 49.13%

                                Individual 95% CIs For Mean Based on
                                Pooled StDev
Level            N    Mean   StDev  --------+---------+---------+---------+-
Prästsjödiket    2  0.1250  0.0354      (--------*---------)
Lass Mass Heden  3  0.1400  0.0700        (--------*--------)
Tjärdal          3  0.0900  0.0361      (--------*------)
Hornmyr          9  0.3267  0.0962                    (---*----)
Gammelhemmet     6  0.4617  0.2082                          (----*----)
Kåddis           3  0.3800  0.0755                     (-------*-------)
                                    --------+---------+---------+---------+-
                                         0.00      0.20      0.40      0.60

Pooled StDev = 0.1256
```

Figure 6.16: Output from Tukey's multiple comparisons regarding the Calcium levels for all Sámi and European sites

```
Source   DF       SS       MS       F       P
Site      6   1.2490   0.2082   11.85   0.000
Error    20   0.3515   0.0176
Total    26   1.6005

S = 0.1326   R-Sq = 78.04%   R-Sq(adj) = 71.45%

                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Level            N    Mean   StDev  ---------+---------+---------+---------+
Prästsjödiket    2  0.0050  0.0071     (-----*------)
Lass Mass Heden  3  0.0333  0.0404       (----*----)
Tjärdal          3  0.0100  0.0100      (----*-----)
Hornmyr          9  0.0578  0.0335          (--*--)
Gammelhemmet     6  0.3400  0.2425                   (--*---)
Kåddis           3  0.6700  0.1500                            (----*-----)
                                    ---------+---------+---------+---------+
                                          0.00      0.30      0.60      0.90
Pooled StDev = 0.1326
```

Figure 6.17: Output from Tukey's multiple comparisons regarding the Phosphorous levels for all Sámi & European sites

The pH values were established from the bulk soil samples to verify whether the podzols soils could be classed as podzolic in accordance with the FAO guidelines however they also revealed an interesting change in acidity between the site types. The average pH values for the A, E and B horizons were calculated and graphed in figure 6.18; A-horizon refers to both A-horizon and anthropogenic topsoil in this instance. The bar graph shows that the acidity at the Sámi sites typically decreases with depth, i.e. down the soil profile. With the input of material to the anthropogenic topsoil at the European sites it is to be expected that the topsoil will be less acidic than at the Sámi sites however the acidity of the whole profile has been affected. The topsoil is far less acidic in the European topsoil than in the podzols of the Sámi sites, see figure 6.18, but instead of decreasing in acidity with depth like the Sámi soils the pH level of the soil remains near constant throughout the profile. This can be linked to the on-going podzolic processes within the anthropogenic topsoil's as identified in the micromorphological analysis whereby the raised pH level of the anthropogenic topsoil is percolating down through the soil profile.

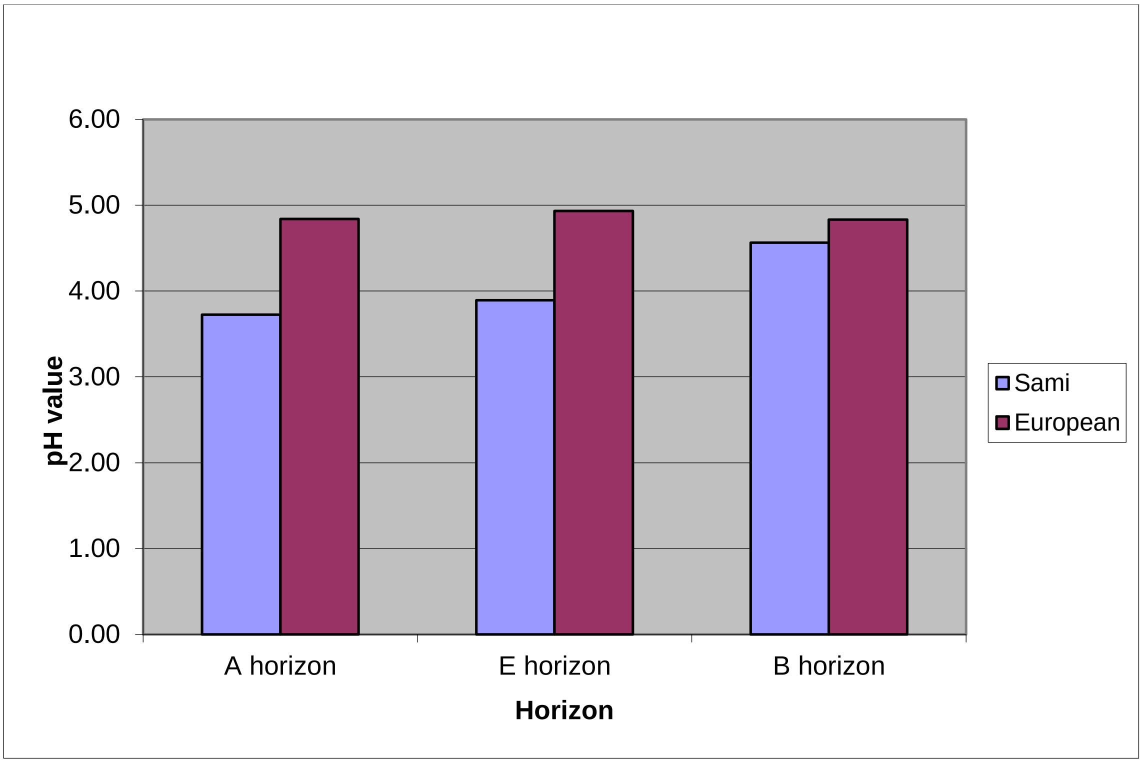


Figure 6.18: The Average pH values for the A, E & B horizons at the Sámi and European sites

6.1.6 Summary

The different types of analysis used throughout link well to give a complete and supporting view of the European footprint on the natural and undisturbed past Sámi landscape. The visual field evidence of anthropogenically deepened topsoils linked well with the micromorphological analysis, which revealed a typical European 'plaggen' style of cultivation; which included the addition of mineral and turf material from elsewhere on the site as evidenced by the inclusion of displaced periglacial silt coatings in the upper anthropogenic topsoil which were also seen in the lower E and B-horizons and the significantly deeper nature of the anthropogenic topsoil compared to the control samples. The location of the added turf material has been evidenced through the inclusion of diatoms at Kåddis to the comparative sampling of peat bogs at Hornmyr. The cultivation of the soil is evident through the high level of mixing and working of the topsoil which is evidenced through the mixed horizons seen in the field evidence as well as in the micromorphology slides through displaced pockets of material and a deeply homogenised microstructure and also through the lack of magnetic susceptibility peaks; a link between the mixing and dilution of charcoal rich soils was made at Hornmyr. The change in chemical properties is also visible in field evidence through the evidence of biological mixing at Kåddis; the podzol soils are too acidic to support macro-fauna so the anthropogenic amendment of the soil has reduced the acidity of the profiles sufficiently to support micro-fauna in the mineral horizons which is not seen in the control samples.

Overall the differences between the Sámi and European evidence is marked, in that the typical Sámi soilscape is undisturbed whereas the European soilscape has been markedly altered from its original state. The one exclusion to this statement is from the chemical analysis which has shown differences in the Titanium, Chloride and Potassium levels, not always significant, from the Sámi, European and control samples. This indicates that this change from the natural, control level is a result of an anthropogenic activity, indicating that element which peak at the Sámi sites, compared to the European sites, can be used as indicators of Sámi activity.

The cultural indicator tables devised for both Sámi and European occupation have been condensed below to highlight the cultural indicators expected, and those which have been confirmed, for both cultures (see table 6.1). This table highlights the differences between the two cultures confirmed indicators and can be used as a soils based model for the identification of each group.

The changes in the titanium levels could be speculated as being anthropogenically related, particularly with Hölzer and Hölzer (1998) stating that the best indicator of anthropogenic activity is the presence of *Plantago* coupled with geochemistry; a *Plantago* seed was identified within the Hornmyr thin section slides. However as titanium levels can also be altered by fires and with the study area being subject to frequent forest fires throughout the study period it cannot be used as a reliable indicator of anthropogenic activity in this area. Likewise the chloride peaks are most likely to be related to the natural decomposition of organic material and cannot be used as indictors of anthropogenic activity for either cultural group. Phosphorus peaks are a common indicator of anthropogenic activity and have been linked to both Sámi and European activity; linked to reindeer faecal deposits at the Sámi sites and added organic material at the European sites.

In relation to the question of interaction, the comparisons between the Sámi and European cultural indicators have revealed two different points. Firstly, as the Sámi had virtually no impact on the soil, there is no way of proving whether or not European settlements have been located on areas of past Sámi activity. However the lack of any inheritable soil qualities from Sámi activity suggests that Europeans would not have sought out to occupy past Sámi activity areas. Conversely, as the only visible indicators of Sámi occupation were hard to see hearth stones, settlers would not have known if they had chosen to settle on an area of past Sámi activity.

Secondly, the European cultural indictors are cultivation based and have had a high impact on the landscape, meaning that the adoption of any cultivation based activity by the Sámi would have been clear. Subsequently, it can be concluded that the Sámi at the study sites did not adopt any form of European cultivation activities on or around their settlement sites. This indicates that, contrary to the literary evidence explored in the earlier chapters which suggested that certain groups of the Sámi began to pick up European traits, both cultures at the sites studied led separate daily lives and only integrated to trade. Overall this indicates that there will be areas of unintentional superimposition, where Europeans have settled on areas of past Sámi activity, but that during the study period the two cultures would have remained separate from one another, with occupation and activity sites being interlinked but not overlapping.

To contextualise, prior to European settlement the Sámi conducted low impact activities on the landscape, leaving a slight footprint from reindeer herding activities in the form of reindeer faecal material and a corresponding phosphorous peak within the soil profile, but overall leaving a pristine landscape, i.e. leaving no inheritable soil qualities. Europeans began to settle within the Sámi landscape and due to the lack of inheritable qualities from Sámi activity, began to superimpose on the pristine Sámi landscape. The agricultural based impact on the landscape from the European settlers markedly changed the past Sámi landscape. However even with this extreme difference, the anthropogenically altered topsoils are still subject to being 'reclaimed' by the inherent podzol soils if not maintained; visual and chemical evidence of a secondary albic horizon forming within the abandoned anthropogenic topsoil of Gammelhemmet. Even with their newly juxtaposed settlement and activity areas, both cultures remained distinct from one another, with no interaction other than for trade purposes.

Table 6.1: Table detailing cultural indicators associated with Sámi and European occupation, estimated from literature review, and those confirmed by analysis of bulk soil and thin sections collected at known Sámi and European sites in northern Sweden

		Visual	Micromorphological											Chemical		Added			
		Ploughmarks	Disturbed horizons	Bone*	Charcoal	Burnt material	Ash	Type 113 fungal spores	Mite excrement	Coprolites	Phytoliths	Coatings & infillings	Microstructure	Increased P	Magnetic susceptibility	Elevated Cl level	Elevated Ti	Elevated Al	Seed
Sámi	Anticipated	×	?	×	✓	?	×	?	?	×	×	?	✓	?	✓	N/A	N/A	N/A	N/A
	Confirmed	×	✓	×	×	×	×	×	✓	✓	×	✓	✓	✓	✓	?	?	×	×
European	Anticipated	✓	✓	×	✓	✓	×	✓	✓	×	×	?	✓	✓	✓	N/A	N/A	N/A	N/A
	Confirmed	*	✓	×	**	×	×	×	×	***	✓	****	✓	✓	×	?	?	✓	✓

*Ploughmarks can be identified by a highly homogenised and compacted microstructure
**Charcoal *may* be used as an indicator of European activity but will be extremely difficult to disentangle from natural charcoal
***Coprolites in the form of manure can be used as an indicator but are difficult to identify due to the level of biological activity and quick decomposition of organic material
****Coatings and infillings only indicative of European cultural activity if dislocated i.e. coatings associated with B horizon present in anthropogenic topsoil and not in control topsoil. Organic carbon coatings are not associated with anthropogenic activity due to the high frequency of forest fires pre-settlement.

Key:

✓	Yes
×	No
?	Unknown

6.2 Testing of soils model

6.2.1 Introduction

In order to check the validity of the soil models developed throughout the earlier chapters the interpretations and results will be tested against independent data. Palynological and entomological data, carried out by Ilse Kammerling at Aberdeen University and Sara Khorasani at Edinburgh University respectively, will be reviewed against the soil findings; the soil, insect and pollen analysis were carried out across overlapping sites in Northern Sweden as part of the 'Footprints on the Edge of Thule: Landscapes of Norse-Indigenous Interaction' research programme, with the aim of collaborating the results for publication. The following results have been kindly provided by the authors for discussion alongside, and to test, the soil results. The full palynological and entomological results and discussion will be available from the authors; the entomological analysis carried out at Gammelhemmet and the palynological analysis carried out at Prästsjödiket, Gammelhemmet and Hornmyr will be discussed here.

6.2.2 Prästsjödiket

A pollen core was taken next to Prästsjödiket Lake, approximately 100m South West of the soil transect. Kammerling has pointed out that the Artemisia seen in the pollen diagram (see figure 6.19) is often used as an indicator of disturbance but stresses that as there are freely growing maritime types so it cannot be used reliably in this context (Kammerling, I. *pers. comm*). However as there is evidence of disturbance within soil profile 1 at Prästsjödiket, see chapter 4.2.4, the presence of Artemisia can be used to support the micromorphological findings. The overall increase in herbs and shrubs post-AD700 (zone 4) indicates an opening up of the vegetation towards a more mosaic cover and the inclusion of type 112 Cercophora fungal spores between 17 and 18cm depth could indicate livestock

(Kammerling, I. *pers. comm*). There was no clear inclusion of reindeer faecal matter, or any coprolites for that matter, within the thin section slides however this does not mean that livestock of any kind were kept on or near the site.

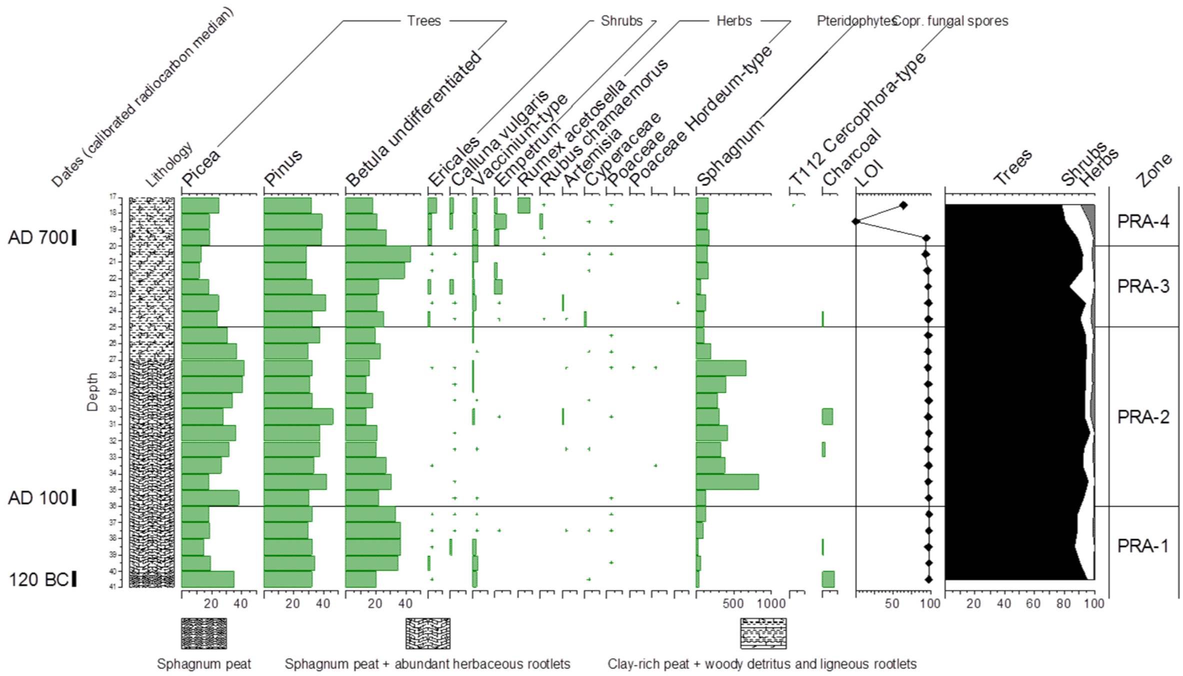


Figure 6.19: Pollen diagram from core taken at Prästsjödiket courtesy of I. Kammerling, 2012

6.2.3 Gammelhemmet

6.2.3.1 Entomological analysis

The entomological diagram is split by species type and sample number and was taken approximately 100m South of the soil transect. The entomological diagram shows a drastic change at sample 3 which is outlined in red (see figure 6.20). This has been depicted by Khorasani as a change from wetland and woodland species to those which are associated with open and arable areas such as the *Otiorhynchus nodosus*, *Chaetocnema hortensis* and *Calathus melanocephalus* beetles and is comparable to medieval farm assemblages in the North Atlantic (Khorasani, S. *pers. comm*). This change was radiocarbon dated to AD1446-

1633 (Khorasani, S. *pers. comm*) which fits with the introduction of European farming in the area.

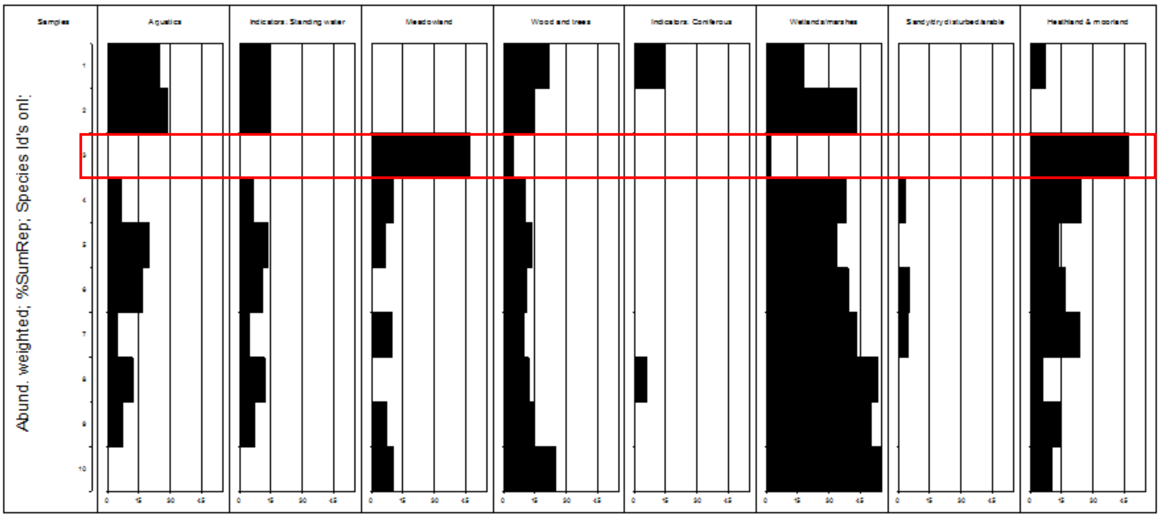


Figure 6.20: Entomological diagram showing species count for each sample taken at Gammelhemmet courtesy of S. Khorasani, 2012

Although when dealing with fauna the climate can always be a factor, the habitat change fits well chronologically with the introduction of European farming to the area and just predates the official occupation date of AD1701 (Andersson, B. *pers. comm*). The change from a wetland and woodland to an open, arable area compliments the soil findings. The field and soil analysis showed a clearing within woodland which was surrounded by peat bogs, giving the wet and woodland habitat seen in the entomological analysis. The micromorphological analysis shows evidence of cultivation through the disruption and mixing of the soil through ploughing and the addition of 'plaggen' type materials which fits with the open, arable interpretation given by Khorasani.

6.2.3.2 Palynological analysis

The pollen core was taken approximately 200m South of the soil transect and due to the preservation of the upper sample was limited to 4cm above the AD1570 date marker; the . The pollen diagram, see figure 21, shows a peak in the *Coprophilous* fungal spores between AD800-1095 and indicates livestock which due to the period and location is most likely to be reindeer (Kammerling, I. *pers. comm*). Post-AD1570 (zone 4) the birch pollen decreases simultaneous to an increase in charcoal. This may be related to the high input of charred material seen in the thin section slides as part of the 'plaggen' style of land management employed at Gammelhemmet which would indicate an earlier occupation date, or it could be related to natural forest fire activity. However as the increase in herbs also fits with the more open and cultivated landscape which is evident from both the micromorphological and entomological analysis indicating that the final phase in the pollen diagram captured the initial stages of site clearance and settlement.

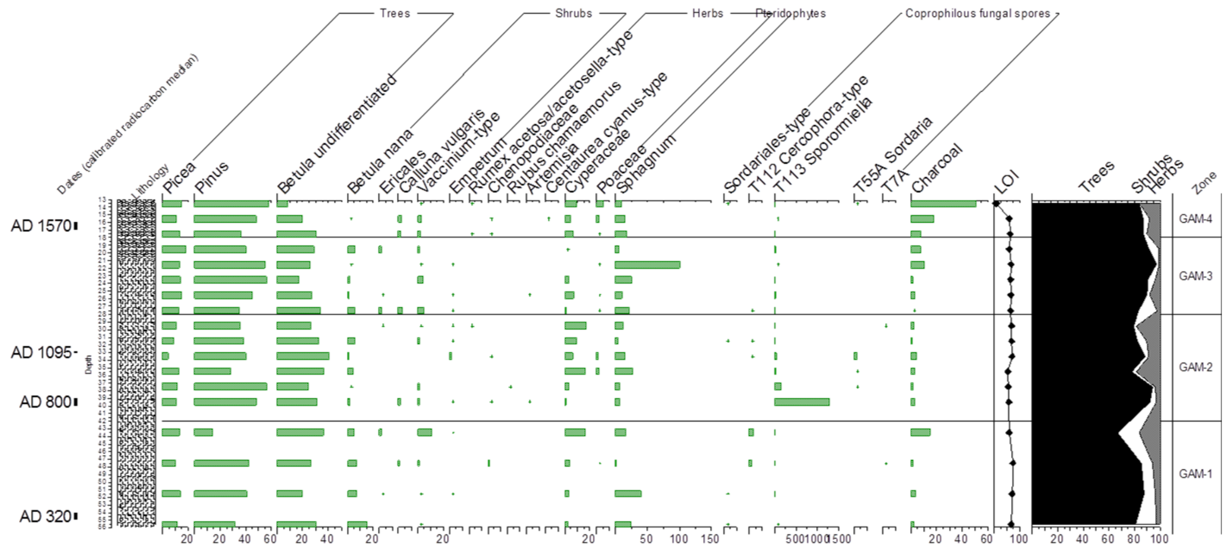


Figure 6.21: Pollen diagram from core taken at Gammelhemmet courtesy of I. Kammerling, 2012

6.2.4 Hornmyr

The pollen core was taken from the peat areas behind the current Hornmyr farm and due to the level of preservation ends a few cm after the last radiocarbon date (AD1570). Therefore it must be assumed that the final phase within the diagram (above AD1570) relates to the environment just before, and during the initial stages of, settlement. The Coprophilous fungal spore count between AD750 and AD1200, similar to the one seen at Gammelhemmet, suggests livestock, which due to the time period and location is most likely to be from reindeer herding (Kammerling, I. *pers. comm*). The fungal spores then disappear post-

AD1200 and the area becomes wetter before grasses pollen increases and wood pollen decreases post-AD1570 which fits with the period of occupation; see zone 4, figure 6.22 (Kammerling, I. *pers. comm*). The opening up of the landscape shown by the increase in grass pollen and decrease in wood pollen fits well with the micromorphological and field evidence. The charcoal peaks in phase 4 of the pollen diagram fit with the burning of the surface vegetation seen in the thin section slides with the overturning and deepening of the topsoil prior to cultivation which would explain the opening up of the landscape and switch from wood to grass pollen seen in the pollen diagram.

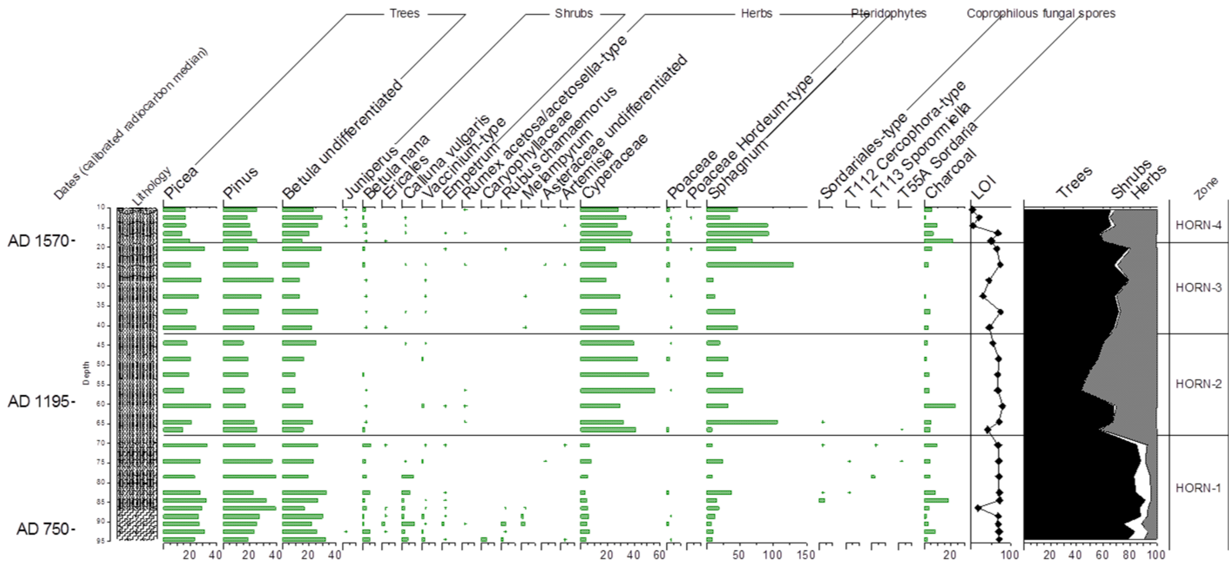


Figure 6.22: Pollen diagram from core taken at Hornmyr courtesy of I. Kammerling, 2012

6.2.5 Summary

The pollen and insect analysis compliments the soil analysis with perhaps Gammelhemmet acting as the best example, where the change in vegetation cover is evident through all three mediums. To recap, the disturbance identified in the micromorphological analysis at profile 1, Prästsjödiket, is supported by the palynological data, the change from wetland and woodland to an open, arable area at Gammelhemmet as identified by the micromorphological and field analysis is supported by both the entomological and palynological data and the change in vegetation from closed woodland to open arable land at Hornmyr as identified in the micromorphological and field evidence is mirrored by the palynological data.

The combination of the different disciplines also strengthens and/or verifies interpretations which were unreliable on their own. For example the occurrence of *Artemisia* within the pollen count at Prästsjödiket could not be used as an indicator of disturbance due to maritime varieties (Kammerling, I. *pers. comm*). However when viewed alongside the disturbance pedofeatures in the micromorphological analysis the occurrence of *Artemisia* in this instance can be used as an indicator of disturbance. However the collaboration of data has also provided information which was not evident in the thin section slides. The occurrence of fungal spores indicative of reindeer herding at Gammelhemmet and Hornmyr is evidence of the past Sámi landscape prior to European settlement, something which was not visible within the thin section slides at the sites. Reindeer faecal matter was identified in the thin section slides at profile 1, Lass Mass Heden, but unfortunately no pollen cores were taken at this site so the two parameters cannot be linked in this instance.

6.3 Summary Conclusions

6.3.1 Objectives

The objectives identified in the opening chapter will be recapped and discussed individually so that each can be addressed appropriately.

Objective 1: To identify and review key information relating to the retention of cultural indicators in podzolic soils, the ‘typical’ activities of both the Sámi and European cultures between AD1200 - AD1800, and the relationship the cultures had with one another.

Chapter 1 contains a comprehensive review of literature relating to the retention of cultural indicators and separate sections looking at the Sámi culture, the European culture and literary evidence of overlap. This was used to create a table identifying the possible cultural indicators for each culture, and those anticipated given their location within an acidic podzol soil.

Chapter 2 then carried this forward by the reviewing the properties and processes of podzol soils and how these are likely to have affected the cultural indicators. The outcome of this was the formation of a podzol model which identified how certain anthropogenic activities could influence the soil. This was supported by a plaggen soil model, derived for the European sites.

Objective 2: To establish what cultural indicators are retained in Scandinavian soils, both podzolic and anthropogenically amended, using field analysis, soil micromorphology and chemical analysis.

This was again carried on from the cultural indicators identified in chapters 1 and 2 with field, micromorphological and chemical analysis being employed to identify any cultural indicators at each site. The results were that a host of traditional cultural indicators were not present, i.e. bone. This does not necessarily mean that these are destroyed in podzolic soils as they may never have been present but as calcitic based materials such as bone are known to break down in acidic conditions it is highly unlikely that any present would have been preserved. The transformation and displacement of charred material within the soil is a further indication of the alterations any surviving indicators are subject too.

Objective 3: To establish what cultural indicators are associated with both Sámi and European occupation through the production of a soils based model.

This has been covered successfully throughout the Sámi and European landscape chapters with soil models listing the observed cultural indicators for each group being formed; these tables are a continuation of those originally formed in chapters 1 and 2 and also show which indicators were anticipated but not present. These models were then tested against independent data in chapter 6 and proved to be reliable.

Objective 4: To use the knowledge gained from the previous aims to look for evidence of interaction between the cultures, and if present, to identify what these changes were and the impact they had on the landscape.

Past Sámi activity underlying the European activity layers at the European sites was not identified but as the Sámi cultural indicator was pastoral (the presence of reindeer faecal material and a corresponding phosphorous peak), this could easily be missed within a cultivation based European soilscape; phosphorous peak could be replicated by, and reindeer faecal fragments destroyed by, European cultivation. Consequently the theory of unintentional superimposition of the European settlers onto the Sámi landscape followed by juxtaposed occupation is proposed but as yet cannot be verified.

6.3.2 Key findings

To recap, the key findings from this have been the formation of the podzol and plaggen soil models in chapter 2 (figures 2.2 and 2.3 respectively), the discovery of Sámi pastoral indicators and the development of reliable soils models for Sámi and European activity in Northern Sweden; in chapters 4 and 5 respectively (see table 6.1 earlier in chapter for combined model). The key finding from the thesis is the identification of the extremely low impact the Sámi had on the landscape; which left a pristine landscape for the European settlers. Their lack of impact on the soil has resulted in the confirmation that the European settlers did not need to settle on Sámi occupation sites as they left no inheritable soil qualities, therefore settlement locations must be the result of other factors.

The only reliable Sámi cultural indicator identified was that of reindeer husbandry through the presence of reindeer faecal material and a corresponding peak in phosphorus. In areas not subject to frequent forest fires titanium peaks and charred horizons within the soil profile may provide further indicators; although both would have been subject to eluviation processes. However, overall the Sámi have had little impact on the soilscape.

The established link between reindeer husbandry and Sámi occupation/activity, and the subsequent reindeer husbandry cultural footprint within the soilscape, is extremely important as it compliments the only other research into the identification of pastoralism using the soil record; the identification of livestock enclosures and pastoral sites in Kenya by Shahack-Gross *et al*, 2003; 2008. The significance of this is that the same identifiers of herding, i.e. dung deposits and phosphorous peaks, identified within this thesis is also visible in herding communities from a different cultural background, and have been retained within a different soil type under different climatic conditions. Subsequently, these identifiers could be extrapolated and applied as indicators of animal husbandry for other pastoralist communities and in various locations.

Regarding the expansion of the European knowledge, the abandoned site of Gammelhemmet provided some particularly interesting findings. The visual, micromorphological and chemical evidence of the secondary albic horizon forming at the top of the abandoned anthropogenic topsoil identifies how quickly even heavily worked, albeit for a short period of time, soils can begin to podzolise; this was identified as a possibility within the podzol model created in chapter 2 even though Yli-Halla and Mokma (2002) suggest that after abandonment a soil cannot fully return to its original state. This, in addition to the micromorphological evidence of on-going podsolization processes in amended topsoils and the high levels of aluminium at the European sites, highlights the fragile nature of the cultural soils in northern Sweden.

6.3.3 Recommendations

The priority for future work would be to check the reliability of titanium and chloride peaks as an indicator of anthropogenic activity in Northern Sweden. This could be achieved by running a series of controlled experiments where several anthropogenic activities could be carried out in order to establish which, if any, significantly altered the titanium and/or chloride levels in the topsoil i.e. if soil erosion or cultivation raised the titanium level of the soil, what volume of marine material is required to increase the chlorine component of the topsoil, if intense burning of biomass at Sámi hearths can cause localised raising of chloride levels in the surrounding topsoil and/or if burning of any sort can chemically alter the presence and availability of chlorides within the topsoil.

As reindeer husbandry has been identified as a reliable indicator of Sámi activity but would be difficult to identify out-with known animal congregation areas such as pens, due to the limited input of manure to the soil and the high level of biological activity identified, work into reindeer lipids in the soil could be a way of expanding this indicator so that it’s more easily identified. This would be particularly interesting if known hunting traps and reindeer pens were sampled. Due to their intensive and contained use the full study of known reindeer hunting traps and pens could identify a set of cultural indicators not present out-with these intensively used localities.

Shahack-Gross et al's work (2008) evidences a link between stable nitrogen and carbon isotopes and animal husbandry. Their methodology could be replicated with bulk soil samples taken from Sámi sites to ascertain whether this indictor would be reliable within the inherent podzol soils of Sweden.

Future work regarding the European side of things would be centred on the re-podsolization of abandoned cultural soils and could be important for identifying past cultural landscapes in Scandinavia. Abandoned sites where the occupation and abandonment dates and land management regimes employed are known could be studied with the acidity levels and secondary albic horizon formation being studied. This way the decrease in acidity in the underlying podzol and any secondary albic horizon formation could be used to provide a rough abandonment date and/or to identify the level of input and/or level of intensity of the site prior to abandonment. It would also be of interest to identify if there is an input threshold which will prevent the re-podsolization of the soil if abandoned.

The difference in 'added' materials at each site also creates a social question of how the settlers obtained the knowledge to create plaggen type soils i.e. did they stumble across plaggen soil management through necessity or was the formation knowledge passed through trade routes from North West Europe? If this knowledge was transferred through trade routes how would it fit with Blume and Leinweber (2004) theory of plaggen soil management spreading from North West Europe?

Bibliography

Abel, W. (1980). Agricultural fluctuations in Europe: from the thirteenth to the twentieth centuries. St. Martin's Press, New York.

Andersen, O. (2011), Reindeer-herding cultures in northern Nordland, Norway: Methods for documenting traces of reindeer herders in the landscape and for dating reindeer-herding activities, *Quaternary International* **238**, 63 – 75.

Andersson, B. (2000), *Rapport över slutundersökning av kokgrop och stensättning på lokalen Prästsjödiket, Raä 600, Umeå sn och kn, Västerbottens län.* Arkeologisk Rapport, Västerbottens museum.

Andersson, B. (2009), personal communication, Skogsmuseet, Lycksele, Sweden.

Anderson, D. E., Goudie, A. S. and Parker, A. G. (2007), Global Environments through the Quaternary, *Links between environmental change and human evolution and society,* 254 – 281, edn. 8. Oxford University Press, New York.

Anderson, H.A., Berrow, M.L., Farmer, V.C., Hepburb, A., Russell, J.D. and Walker, D.A. (1982). A reassessment of podzol formation processes. *Journal of Soil Science* **33**, 125 – 136.

Antonson, H. (2009), The extent of farm desertion in central Sweden during the late medieval agrarian crisis: landscape as a source, *Journal of Historical Geography* **35**.4, 619 – 641.

Aronsson, K, (1991), Readings in Saami history, culture and language II, *Forest Saami reindeer herding, AD 0-1800* (ed. Kvist, R), 31 – 40, edn. 12. Centre for Arctic Cultural Research Miscellaneous Publications, University of Umea, Umea, Sweden

Awty, B.G. (2007), The Development and Dissemination of the Walloon Method of Ironworking, *Technology and culture* **48**.4, 783 – 803.

Badou, E. and K.H. Dahlstedt, Nord-Skandinaviens historia i tvärvetenskaplig belysning. Umeå, Sweden.

Barrett, J., Johnstone, C., Harland, J., Van Neer, W., Ervynck, A., Makowiecki, D., Heinrich, D., Hufthammer, A.K., Enghoff, I.B., Amundsen, C., Christiansen, J.S., Jones, A.K.G., Locker, A., Hamilton-Dyer, S., Jonsson, L., Läugas, L, Roberts, C. and Richards, M. (2008), Detecting the Medieval Cod Trade: A New Method and First Results, *Journal of Archaeological Science* **35**, 850 – 861.

Barrett, L.R. and Schaetzl, R.J. (1992), An examination of podzolization near Lake Michigan using chronofunctions, *Canadian Journal of Soil Science* **72**, 527 – 541.

Baudou, E., Engelmark, R., Liedgren, L., Segerström, U. and Wallin, J.E. (1991), Järnåldersbygd i Österbotten: en ekologisk-arkeologisk studie av bosättningskontinuitet och resursutnyttjande. Scriptum, Vaasa.

Bergman, I., Ostlund, L., Zackrisson, O. and Liedgren, L. (2006), Stones in the snow: A Norse fur traders' road into Sami country, *Antiquity* **81**, 397 – 408.

Bertelsen, R. and Urbańczyk, P. (1988), Two perspectives on Vågan in Lofoten, *Acta Borealia* **5**, 98 - 110

Beskorovainaya, I.N. and Tarasov,P.A. (2009), Influence of fire on ecological conditions of sandy podzol soils in pine stands of Central Siberia. Proceedings 3rd Australian New Zealand Soils Conference, University of Sydney, Australia, Symposium 12: Soil health, quality and function.

Bjørnstad, G., Flagstad, Ø., Hufthammer, A.K. and Røed, K.H. (2012), Ancient DNA reveals a major genetic change during the transition from hunting economy to reindeer husbandry in northern Scandinavia, *Journal of Archaeological Science* **39**, 102 – 108.

Blume, H. and Leinweber, P. (2004), Plaggen soils: landscape history, properties, and classification, *Journal of Plant Nutrition and Soil Science* **167**, 319 – 327.

Brander, R., Joelsson, J., Löfqvist, M. and Niemi, V. (2001), Kulturarvet I skog och bygd, Delrapport. Redovisning av inventeringen på kartblad 20K 7c och 20K 7d, Västerbotten museum, Sweden.

Bratrein, H.D. (1981), Settlement and Settlement Continuity in the Parish of Karlsoey in the Middle Ages, *Norwegian Archaeological Review* **14**.2, 106 – 116.

Broadbent, N.D. (2004), Saami prehistory, identity and rights in Sweden, The Resilient North-Human Responses to Global Change.

Bryant, R.G. and Davidson, D.A. (1996), The Use of Image Analysis in the Micromorphological Study of Old Cultivated Soils: An Evaluation Based on Soils from the Island of Papa Stour, Shetland, *Journal of Archaeological Science* **23**, 811 – 822.

Buurman, P. and Jongmans, A.G. (2005), Podzolisation and organic matter dynamics, Geoderma 125, 71 – 83.

Carcaillet, C. (2001), Soil particles reworking evidences by AMS ^{14}C dating of charcoal, *Earth and Planetary Sciences* **332**, 21 – 28.

Coleman, D.C. and Fry, B. (1991), Carbon Isotope techniques. Academic Press, San Diego.

Conry, M.J. and MacNaeidhe, F. (1999), Comparative nutrient status of a peaty gleyed podzol and its plaggen counterpart on the Dingle peninsula in the south-west of Ireland, *European Journal of Agronomy* **11**, 85 – 90.

Courty, M.A., Macphail, R.I. and Wattez, J. (1991), Soil Micromorphological indicators of pastoralism; with special reference to Arene Candide, Finale Ligure, Italy, *Rivista di Studi Liguri* **LVII**, 127 – 150.

Creutzberg, D. and de Bakker, H. (1988), Soil Management of Spodosols with Plaggen Epipedon (Presented at Fifth International Soil Correlation Meeting (ISCOM), Lake Placid USA, October 1988). Working Paper 88/06, ISRIC, Wageningen.

Cruickshank, J.G. and Cruickshank, M.M. (1981), The development of humus-iron podsol profiles, linked by radiocarbon dating and pollen analysis to vegetation history, *OIKOS* **36**, 238 – 253.

Cunningham, D.A., Collins, J.F. and Cummins, T. (2001), Anthropogenically-triggered iron pan formation in some Irish soils over various time spans, *Catena* **43**, 167 – 176.

Czimczik, C.I., Schmidt, W.I. and Schulze, E.D. (2005), Effects of increasing fire frequency on black carbon and organic matter in Podzols of Siberian Scots pine forests, *European Journal of Soil Science* **56**, 417 – 428.

Dalton, G. (1967), Tribal and peasant economies: readings in economic anthropology. Garden City, New York.

Davidson, D.A. and Simpson, I.A. (1984), The Formation of Deep Anthropogenic Topsoils in Orkney, *Earth Surface Processes and Landforms* **9**, 75 – 81.

Davidson, D.A., Dercon, G., Simpson, I.A., Dalsgaard, K., Spek, T. and Plant, D.A. (2007), The Identification and Significance of Inputs to Anthrosols in North-West Europe, *Società Toscana di Scienze Naturali* **112**, 79 – 83.

De Coninck, F. (1980), Major mechanisms in formation of spodic horizons, *Geoderma* **24**, 101 – 128.

Delhaize, E. and Ryan, P.R. (1995), Aluminum toxicity and tolerance in plants, Plant *Physiology* **107**, 315 – 321.

Dercon, G., Davidson, D.A., Dalsgaard, K., Simpson, I.A., Spek, T. and Thomas, J. (2005), Formation of sandy anthropogenic soils in NW Europe: identification of inputs based on particle size distribution, *Catena* **59**, 341 – 356.

Eiermann, M. (2008), The coastal Sami of Norway, Sámi culture, available at http://www.utexas.edu/courses/sami/dieda/hist/nor-sami.htm, accessed on 4th April 2009.

Elliot, G. (1996), Microfabric evidence for podzolic soil inversion by solifluction processes, *Earth Surface Processes and Landforms* **21**, 467 – 476.

Engberg, E. (2006), Life on the Edge. Rural Poverty and vulnerability in XIXth century Northern Sweden, *Annanles De Démographie Historique* **1**, 31 – 57.

Englemark, R. (1981), Carbonized plant material from an early Iron Age in N Sweden, *Wahlenbergia* **7**, 39 – 43.

Englemark, R. (1991), The archaeology of the cultural landscape, *A review of the farming economy in South Scania based on botanical evidence*, Acta Archaeologica Lund 4, 369 – 375 (ed. Callmer, J., Larsson, L. and Stjernquist, B). Almqvist and Wiksell, Stockholm.

Esdale, J.A., Le Blanc, R.J. and Cinq-Mars, J. (2001), Periglacial geoarchaeology at the Dog Creek site, Northern Yukon, *Geoarchaeology* **16**.2, 151 – 176.

Espelund, A. (1985), A Brief account of Ironmaking in Norway in Prehistoric and Historic Times - Recent times, experimental work, Medieval Iron in Society II.Papers and discussions at the symposium in Norberg, 39 – 43.

Fageria, N. K., Baligar, C. and Zobel, R.W. (2002), Yield, Nutrient Uptake, and Soil Chemical Properties as Influenced by Liming and Boron Application in Common Bean in a No- Tillage System, *Communications in Soil Science and Plant Analysis* **38**, 1637 – 1653.

FAO, (2006). World reference base for soil resources. World Soil Resources Reports No. 103. FAO, Rome.

Farmer, V.C., McHardy, W.J., Robertson, L., Walker, A. and Wilson, M.J. (1985), Micromorphology and submicroscopy of allophane and imogolite in a podzol Bs horizon; evidence for translocation and origin, *Journal of Soil Science* **36**, 87 – 95.

Fathollahzadeh, H., Mobli, H. and Tabatabaie, S.M.H. (2009), Effect of ploughing depth on average and instantaneous tractor fuel consumption with three-share disc plough, *Int. Agrophysics* **23**, 399 – 402.

Fitzpatrick, E.A. (1980), Soils: Their formation, classification and distribution, Longman, London.

Fox and Tournocai, (1990), Micromorphology: basic & applied science, Applications to Pedology, 123 – 320 (ed. Douglas, L.A.). Proceedings of the VIIIth International Working Meeting of Soil Micromorphology, San Antonio, Texas – July 1988. Elsevier, New York.

French C.A.I. (2003). Geoarchaeology in action: Studies in soil micromorphology and landscape evolution. London: Routledge.

Garland, A. N. and Janaway, R. C. (1989), Burial Archaeology: Current Research, Methods and Developments, *The taphonomy of inhumation burials*, 15 – 37 (ed. Roberts, C., Lee, F. and Bintliff, J.). BAR British Series 211.

Geel, B., Buurman, J., Brinkkemper, O., Schelvis, J., Aptroot, A., Van Reenen, G. and Hakbijl, T. (2003), Environmental reconstruction of a Roman Period settlement site in Uitgeest (The Netherlands), with special reference to coprophilous fungi, *Journal of Archeological Science* **30**, 873 – 883.

Genealogy record (2012), Genealogy record for Olof Andersson of Hornmyr, available at http://www.geni.com/people/Olof-Andersson/6000000007950466274, accessed on 15th June 2012.

Gjerset, K. (1915), Histoey of the Nokwegian People, The Macmillan Company, Toronto, Canada.

Google Maps (2013), Satelitel map images from saved site locations, available at https://maps.google.co.uk/maps?hl=en&ie=UTF-8&tab=wl&authuser=0, accessed on 1st May 2013.

Gordon, R.B. and Reynolds, T.S. (1986), Medieval iron in society - Norberg, Sweden, May 6-10, 1985, *Technology and culture* **27**.1, 110 – 117.

Görres, M. and Frenzel, B. (1997), Ash and Metal Concentrations in Peat Bogs as Indicators of Anthropogenic Activity, Water, *Air and Soil Pollution* **100**, 355 – 365.

Gothe, R. (1948), Finnkolonisationen inom Ångermanland, Södra Lappmarker och Jämtland, Författarens Förlag, Stockholm.

Goudie, A. (1990), The Human Impact on the Natural Environment, *The human impact on vegetation*, 3rd edn. 25 – 75. Blackwell, Oxford.

Grandström, A., Goldammer, J.G. and.Furyaev, V.V (eds.) (1996), Fire in Ecosytems of Boreal Eurasia, *Fire Ecology in Sweden and Future Use of Fire for Maintaining Biodiversity*, 445-452. Kluwer Academic Publishers.

Grandström, A. (2001), Fire management for biodiversity in the European boreal forest, *Scandinavian Journal of Forest Research* **3**, 62 – 69.

Hatt, G. (1919), Notes on reindeer nomadism, Memoirs of the American Anthropological Association 6.2, Washington D.C.

Hinsinger, P. (2001), Bioavailability of soil inorganic P in the rhizosphere as affected by root-induced chemical changes: a review, *Plant and Soil* **237**.2, 173 – 195.

Hofstra, T. and Samplonius, K. (1995), Viking Expansion Northwards: Medieval Sources, *Arctic* **48**, 235 – 247.

Hodgins, G.W.L., Thorpe, J.L., Coope, G.R. and. Hedges, R.E.M (2001), Protocol development for purification and characterisation of sub-fossil insect chitin for stable isotopic analysis and radiocarbon dating, *Radiocarbon* **43**, 199 – 208.

Hölzer, A. and Hölzer, A. (1998), Silicon and titanium in peat profiles as indicators of human impact, *The Holocene* **8**.6, 685 – 696.

Howie, K. (2012), personal communication, University of Stirling, Stirling, UK.

Hubbe, A., Chertov, O., Kalinina, O., Nadporozhskaya, M., Tolksdorf-Lienemann, E. and Giani, L. (2007), Evidence of plaggen soil;s in European North Russia (Arkhangelsk region), *Journal of Plant Nutrition and Soil Science* **170**, 329 – 334.

Huttunen, P. (1980), Early land use, especially slash-and-burn cultivation in the commune of Lammi, Southern Finland, interpreted mainly using pollen and charcoal analyses, *Acta Botanica Fennica* **113**, 1 – 45.

Ismail-Meyer, K. (2010), personal communication, Institut für prähistorische und naturwissenschaftliche Archäologie (IPNA), Basel, Switzerland.

Ivanov, A.I (2000), Some Regularities in Changes in the Acidic-Base Status of Sandy Loamy Soddy-Podzolic Soils under Agricultural Use, *Eurasian Soil Science* **33**.2, 148 – 152.

Jansen, B., Nierop, K.G.J. and Verstraten, J.M. (2002), Influence of pH and metal/carbon ratios on soluble organic complexation of Fe(II), Fe (III) and Al(III) in soil solutions determined by diffusive gradients in thin films, *Analytica Chimica Acta* **254**, 259 – 270.

Jansen, B., Nierop, K.G.J. and Verstraten, J.M. (2004), Mobilization of dissolved organic matter, aliminium and iron in podzol eluvial horizons as affected by formation of metal-organo complexes and interactions with solid soil material, *European Journal of Soil Science* **55**, 287 – 297.

Johansen, O.S. and Vorren, K.D. (1986), The prehistoric expansion of farming into Arctic Norway: A chronology based on C^{14} dating, *Radiocarbon* **28**, 739 – 747.

Jauhiainen, E. (1972), Rate of podzolization in a dune in northern Finland. *Commentationes Physico-Mathematicae* **42**, 33 – 44.

Kammerling, I. (2012), personal communication, University of Aberdeen, Aberdeen, UK.

Kanev, K.K. and Kazakov,V.G. (2005), Transformation of the Properties of Soddy-Podzolic Soils under the Impact if Drainage and Cultivation, *Eurasian Soil Science* **38**.6, 664 – 675, 750 – 761..

Keller, C. (2008), Furs, fish and Ivory - Medieval Norsemen at the Arctic fringe.

Kemp, R.A. (1985), Soil Micromorphology and the Quaternary - Q.R.A. Technical Guide No.2, *Introduction to the systematic description of thin sections*, 3rd edn. 11 – 17. Quaternary Research Association, London.

Kemp, R.A. (1985), Soil Micromorphology and the Quaternary - Q.R.A. Technical Guide No.2, *Systematic description and interpretation of thin sections. 1. Structure, groundmass and organic components*, 18 – 31. Quaternary Research Association, London.

Kemp, R.A. (1985), Soil Micromorphology and the Quaternary - Q.R.A. Technical Guide No.2, *Systematic description and interpretation of thin sections. 2. Concentration (and depletion) features*, 32 – 55. Quaternary Research Association, London.

Kemp, R.A. (1985), Soil Micromorphology and the Quaternary - Q.R.A. Technical Guide No.2, *Presentation of Micromorphological data*, 56 – 59. Quaternary Research Association, London.

Kemp, R.A. (1985), Soil Micromorphology and the Quaternary - Q.R.A. Technical Guide No.2, *Quaternary Soils and Micromorphology*, 60 – 71. Quaternary Research Association, London.

Keppler, F. and Biester, H. (2003), Peatlands: a major sink for naturally formed organic chlorine, *Chemosphere* **52**, 451 – 453.

Khorasani, S. (2012), personal communication, University of Edinburgh, Edinburgh, UK.

Kooistra1, M.J. and Pulleman, M.M. (2010), Interpretation of Micromorphological Features of Soils and Regoliths, *18 – Features Related to Faunal Activity*, 397 – 418.

Kovar, A.J. (1964), Problems in radiocarbon dating at Teotihucan, *American Antiquity* **31**, 427 – 430.

Kristiansen, S.M. (2000), Soil variations under ancient woodland in Denmark: Natural and anthropogenic causes, Doctoral thesis, 1 – 149. University of Aarhus, Denmark.

Kuvaeva, V.Y. and Frid, A.S. (2001), Dynamics of the Organic Matter Associated with Finely Dispersed Particles of Soddy-Podzolic Soils in Conditions of Long-Term Experiments, *Eurasian Soil Science* **34**, 43 – 51.

Kuznetsova, I.V., Utkaeva,V.F. and Bondarev, A.G. (2009), Assessment of Changes in the Physical Properties of Plowed Loamy Soddy-Podzolic Soils in the Nonchernozemic Zone of European Russia under the Impact of Anthropogenic Loads, *Eurasian Soil Science* **42**, 137 – 146.

Kvist, R. (1992), Swedish Sami Policy, 1550-1990, Readings in Saami history, culture and language III, Centre for Arctic Cultural Research, 63 – 77.

Länsstyrelsen/Skogsmuseet (1999), Information boards, Gammelhemmet, Sweden.

Laufer, B. (1917), The reindeer and its domestication, Memoir 4, American Anthropological Association, Lancaster PA.

Lindberg, T. (2009), personal communication, Hornmyr, Sweden.

Lindholm (2008), Swedish Tourist Board, Hornmyr, available at http://www.visitlycksele.se/en/component/content/article/170-hornmyr, accessed on 19th June 2009.

Litvinovich, A.V., Pavlova, O.Y. and Chernov, D.V. (2002), Change in the humus state of sod-podzolic sandy soil after cessation of anthropogenic action, *Russian Agricultural Sciences* **12**, 16 – 18.

Lloyd, J. (2002), The CO2 dependence of photosynthesis, plant growth responses to elevated CO2 concentrations and their interaction with soil nutrient status, II. Temperate and boreal forest productivity and the combined effects of increasing CO2 concentrations and increased nitrogen deposition at a global scale, *Functional Ecology* **13**.4, 439 – 459.

Lycksele sameförening och Skogmuseet (2000). Information boards, Skogsmuseet, Lycksele, Sweden.

Macphail, M.A., Courty, M.A. and Gebhardt, A. (1990), Soil micromorphological evidence of early agriculture in north-west Europe, *World Archaeology* **22**, 53 – 68.

Macphail, R. (2011), personal communication, University College London, London, UK.

Madsen, H.B. (1983), Himmerlands jordbundsforhold et regionalt studie omhandlende jordbundsudvikling,klassifikation, afgrødernes rodudvikling og jordens plantetilgængelige vand, *Folia Geographica Danica Tom* **XVI**, 1 – 329.

Manker, E. and Vorren, Ø (1962), Lapp Life and Customs. Oxford University Press, London.
Mathiesen, P., Holm-Olsen, I.M., Søbstad, T. and Bratrein, H.D (1981), The Helgøy Project: An interdisciplinary Study of Past Eco-Ethnic Processes in the Helgøy Region, Northern Troms, Norway, *Norwegian Archaeological Review* **14**, 77 – 101.

Mats, N. and Granström. A. (2000), Numbers and sizes of fires: Long term spatially explicit fire history in a Swedish Boreal Landscape, *Ecology* **81**, 1484 – 1499.

Matthews, W., French, C.A.I., Lawrence, T., Cutler, D.F. and Jones, M.K. (1997), Microstratigraphic traces of site formation processes and human activities, *World Archaeology* **29**.2, 281 – 308.

McKeague, J.A., Wang, C., Coen, G.M., DeKimpe, C.R., Laverdiere, M.R., Evans, L.J., Kloosterman, B. and Green, A.J. (1983), Testing chemical criteria for spodic horizons on podzolic soils in Canada, *Soil Science Society of America* **47**, 1052 – 1054.

Meriot, C. (1984), The Sammi Peoples from the Time of the Voyage of Ottar to Thomas von Westen, *Arctic* **37**, 373 – 384.

Miller, C. (2011), personal communication, University of Tübingen, Germany.

Mineev, V.G., Gomonova, N.F., Zenova, G.M. and Skvortsova, I.N. (1999), Changes in the Properties of Soddy-Podzolic Soil and It's Microbocenosis under Intensive Anthropogenic Impact, *Eurasian Soil Science* **32**, 413 – 417.

Mirov, N.T. (1945), Notes on the Domestication of Reindeer, *American Anthropologist* **47**, 393 – 408.

Moen, A. (1999), National Atlas of Norway – Vegetation, Norwegian mapping authority, Hønefoss.

Mokma, D.L. and Buurman, P. (1982), Podzols and podsolization in tempertate regions. ISM momograph 1, International Soil Museuem. Wageningen.

Mokma, D.L. (1992), Evaluation of recent proposalsto change chemical criteria for spodic horizons, *Soil Survey Horizons* **33**, 12 – 16.

Mokma, D.L., Yli-Halla, M. and Lindqvist, K. (2004), Podzol formation in sandy soils of Finland, *Geoderma* **120**, 259 – 272.

Muga, D.A. (1986), A Commentary on the Historical Transformation of the Sami Communal Mode of Production, *Journal of Ethnic Studies* **14**, 111 – 121.

Mulk, I. (1991), Readings in Saami history, culture and language II , *Sirkas - A mountain Saami hunting society in transition, AD500-1500*, 41 – 58 (ed. Kvist, R.). Centre for Arctic Cultural Research Miscellaneous Publications, Univeristy of Umeå, Sweden.

Mundal, E. (2000), Coexistence of Saami and Norse culture - reflected and interpreted by Old Norse myths, Proceedings of the 11th International Saga Conference, 346 – 355.

Murphy, C.P. (1986), Thin section preparation soils and sediments. AB Academic Publishers, Berkhamsted.

Nordstrom, B.J. (2000), Scandinavia since 1500, *Scandinavia before the modern era*. University of Minnesota Press, Minneapolis.

Oliver, N. (2010), Landscapes and Social Transformations on the Northwest Coast: Colonial Encounters in the Fraser Valley (Archaeology of Colonialism in Native North America). University of Arizona Press, Tucson.

Olsen, B. (1999), Belligerent Cheiftains and Oppressed hunters? - Changing conceptions of Inter-Ethnic Relationships in Northern Norway during the Iron Age and eraly Medieval Period, The danish national Museum and Danish Polar centre, 28 – 43.

Orlova, L.A. and Panychev, V.A. (1993), The Reliability of Radiocarbon Dating buried Soils, *Radiocarbon* **35**.3, 369 – 377.

Out, W. (2009), Sowing the seed ?: human impact and plant subsistence in Dutch wetlands during the Late Mesolithic and Early and Middle Neolithic (5500-3400 cal BC), Doctoral thesis. Leiden University Press, Netherlands.

Paine, R. (1957), Coast Lapp Society. Tromsø Museum, Norway.

Perdikaris, S. (1999), From cheifly provisioning to commerical fishery: long-term economic change in Arctic Norway, *World Archaeology* **30**, 388 – 402.

Petersen, L. (1976), Podzols and podzolisation. Royal Veterinary and Agricultural University, Copenhagen, Denmark.

Pierce, F.J., W.E. Larson, R.H. Dowdy, and Graham, W.A.P. (1983), Productivity of soils: Assessing long-term changes due to erosion. *Journal of Soil and Water Cons.* **38**.1, 39 – 44.

Ramsay, S. (2009), personal communication, University of Glasgow, Glasgow, UK.

Rapp, G. and Hill, C.L. (1998), Geo-archaeology: The earth science approach to archaeological interpretation. Yale University Press, London.

Porch, N. and Kershaw, A.P. (2010), Altered ecologies : fire, climate and human influence on terrestrial landscapes, *Comparative AMS 14C dating of plant macrofossils, beetles and pollen preparations from two late pleistocene sites in southeastern Australia*, 395 – 404 (ed. Haberle, S., Stevenson, J. and Prebble, M.), ANU E Press, Canberra, A.C.T.

Protz, R., Ross, G. J., Martini, I.P., and Terasmae, J. (1984), Rate of podzolic soil formation near Hudson Bay, Ontario, *Canadian Journal of Soil Science* **64**, 31 – 49.

Regnell, M. (2003), Charcoals from Uppåkra as Indicators of Leaf Fodder, Uppåkrastudier 7, Centrality – Regionality, 105-115.

Renouf, M.A.P., Bell, T. and Macpherson, J. (2009), Hunter-Gatherer Impact on Subarctic Vegetation: Amerindian and Palaeoeskimo Occupations of Port au Choix, Northwestern Newfoundland, *Arctic Anthropology* **46**, 176 – 190.

Roberts, N. (2000), The Holocene: An Environmental History, *Reconstructing Holocene Environments*, 8 – 54, 2nd volume. Blackwell Publishing, Oxford.

Røed, K.H., Flagstad, Ø., Bjørnstad, G. and Hufthammer, A.K. (2011), Elucidating the ancestry of domestic reindeer from ancient DNA approaches, *Quaternary International* **238**, 83 – 88.

Schia, E. (1994), Urban Oslo and its relation to rural production in the hinterland-An archaeological view In Hall AR and Kenward HK (editors) Urban-rural connexions: perspectives from environmental archaeology, *Symposia for the Association for Environmental Archaeology* **12**, 1 – 12.

Schneider, C. and Fry, G. (2005), estimating the consequences of land-use changes on butterfly diversity in a marginal agricultural landscape in Sweden, *Journal for Nature Conservation* **13**, 247 – 256.

Segerström, U. (1990), The post-glacial history of vegetation and agriculture in the Luleälv river valley, *Archaeology in the Environment* **7**, 1 – 80.

Segerstrom, U. and Emanuelsson, M. (2002), Extensive forest grazing and hay-making on mires - vegetation changes in south-central Sweden due to land use since Medieval times, *Vegetation History and Archaeobotany* **11**, 181 – 190.

Shahack-Gross, R., Simons, A. and Ambrose, S.H. (2003), Geo-Ethnoarchaeology of Pastoral Sites: The Identification of Livestock Enclosures in Abandoned Maasai Settlements, *Journal of Archaeological Science* **30**, 439 – 459.

Shahack-Gross, R., Macrshall, F. and Weiner, S. (2008), Identification of pastoral sites using stable nitrogen and carbon isotopes from bulk sediment samples: a case study in modern and archaeological pastoral settlements in Kenya, *Journal of Archaeological Science* **35**, 983 – 990.

Simpson, I.A. (1993), The chronology of anthropogenic soils formation in Orkney, *Scottish Geographical Magazine* **109**, 4 – 11.

Simpson, I.A. (1995), Establishing time-scales for early cultivated soils in the Northern Isles of Scotland, *Scottish Geographical Journal* **111**, 184 – 186.

Simpson, I.A. (1997), Relict Properties of Anthropogenic Deep Top Soils as Indicators of Infield Management in Marwick, West Mainland, Orkney, *Journal of Archaeological Science* **24**.4, 365 – 380.

Simpson, I.A. and Bryant, R.G. (1998), Relict soils and early arable land management in Lofoten, Norway, *Journal of Archaeological Science* **25**, 1185 – 1198.

Simpson, I.A, Perdikaris, S., Cook, G., Campbell, J.L. and Teesdale, W.J. (2000), Cultural sediment analyses and transitions in early fishing activity at Langenesvaeret, Vesteralen, Northern Norway, *Geoacrchaeology: An international Journal* **15**, 743 – 763.

Simpson, I.A. and Adderley, W.P. (2011). Hybrid Spaces: Medieval Finnmark and the Archaeology of Multi-Room Houses, *Activities and accumulations - Micromorphological analyses of archaeological sediments from multi-room houses in Finnmark, Norway* 267-286. (ed. Olsen, B., Urbanczyk, P. and Amundsen, C.P.). Novus forl. Instituttet for sammenlignende kulturforskning, Oslo.

Simpson, I.A. (2012), personal communication, University of Stirling, Stirling, UK.

Skandfer, M. (2009), Ethics in the Landscape: Prehistoric Archaeology and Local Sámi Knowledge in Interior Finnmark, Northern Norway, *Arctic Anthropology* **46**, 89 – 102.

Skovgaard-Petersen (2002), Historiography at the Court of Christian IV (1588-1648): Studies in the Latin Histories of Denmark by Johannes Pontanus and Johannes Meursius, Museum Tusculanum Press, Denmark.

Snakin, V.V. and Prisyazhnaya, A.A. (1997), Qualitative assessment of the degree of anthropogenic changes in soil by analysing the in situ composition of the soil liquid phase, *Geoderma* **75**, 279 – 287.

Stoops, G. (2003), Guidelines for analysis and description of soil and regolith thin sections (ed. M.J. Vepraskas). Soil Science Society of America.

Sturluson, S. (2000), Heimskringla; or The Chronicle of the Kings of Norway, Blackmask Online.

Swedish Geological Society (2010), Bedrock maps for Västerbotten county. Geological Survey of Sweden, Uppsala, Sweden.

Tipping, R. (1998), Native woodland restoration in Southern Scotland: principles and practice, *The application of paleoecology to native woodland restoration: Carrifran as a case-study*, 9 – 21 (ed. Newton, A.C. and Ashmole, P.). Occasional paper no.2, The Borders Forest trust, Jedburgh.

Tipping, R., Buchanan, R., Davies, A. and Tisdall, E. (1999), Woodland biodiversity, palaeo-human ecology and some implications for conservation management, *Journal of Biogeography* **26**, 33 – 43.

Tonneijck, F.H. and Jongmans, A.G. (2008), The influence of bioturbation on the vertical distribution of soil organic matter in volcanic ash soils: a case study in northern Ecuador, *European Journal of Soil Science* **59**, 1063 – 1075.

UNEP (United Nations Environment Programme) (2011), World Conservation Monitoring Centre, High Coast: Kvarken Archipelago, World Heritage Sites, Conservation Commons.

Urbanczyk, P. (1992), Medieval Arctic Norway. Semper, California.

Vainshtein, (1980), Nomads of South Siberia (ed. Humphrey, C.), Cambridge Studies in Social Anthropology, Cambridge.

Van Hees, P., Lundström, U., Danielsson, R. and Nyberg, L. (2001), Controlling mechanisms of aluminium in soil solution - an evaluation of 180 podzolic forest soils, *Chemosphere* **45**, 1091 – 1101.

Van Hoof, T.B., Bunnik, F.P.M., Waucomont,J.G.M., Kurschner,W.M. and Visscher,H. (2006), Forest re-growth on medieval farmland after the Black Death pandemic - Implications for atmospheric CO2 levels, *Palaeogeography Palaeoclimatology Palaeoecology* **237**, 396 – 411.

Västerbotten museum (1991), Information boards, Baggböle, Sweden.

Vorren, K. (1979), Anthropogenic Influence on the Natural Vegetation in Coastal North Norway during the Holocene. Development of Farming and Pastures, Norwegian *Archaeological Review* **12**, 1 – 21.

Vorren, K. and Johansen, O.S. (1986), The Prehistoric expansion of Farming into "Arctic" Norway: A Chronology Based on C14 Dating, *Radiocarbon* **28**, 739 – 747.

Wallin, J. (1996), History of sedentary farming in Ångermanland Northern Sweden during the Iron Age and Medival period based on pollen analytical investigation, *Vegetation History and Archaeobotany* **5**, 301 – 312.

Wallin, J.E. and Segerström, U. (1994), Natural resources and agriculture during the Iron Age in Ostrobothnia, western Finland, investigated by pollen analysis, *Vegetation History and Archaeobotany* **3**, 89 – 105.

Wheelersburg, R.P. (1991), Uma Saami Native Harvest Data Derived from Royal Swedish Taxation Records 1557-1614, *Arctic* **44**, 337 – 345.

Wiklund, K. B. (1923), The Lapps in Sweden, *Geographical Review* **13**, 223 – 242.

Wilson, C.A., Davidson, D.A. and Cresser, M.S. (2005), An evaluation of multi-element analysis of historic soil contamination to differentiate space use and former function in and around abandoned farms, *The Holocene* **15**, 1094 – 1099.

Wolf, K. and Pulsiano, P (1993), Medieval Scandinavia: An encyclopedia, Garland Publishing, Inc, New York.

Yli-Halla, M. and Mokma, D.L (2001), Soil Classification, *Problems encountered when classifying the soils of Finland*, (ed. Micheli, E., Nachtergaele, F.O., Jones, R.J.A. and Montanarella, L.).183 – 189. Office for Official Publications of the European Communities, Luxembourg.

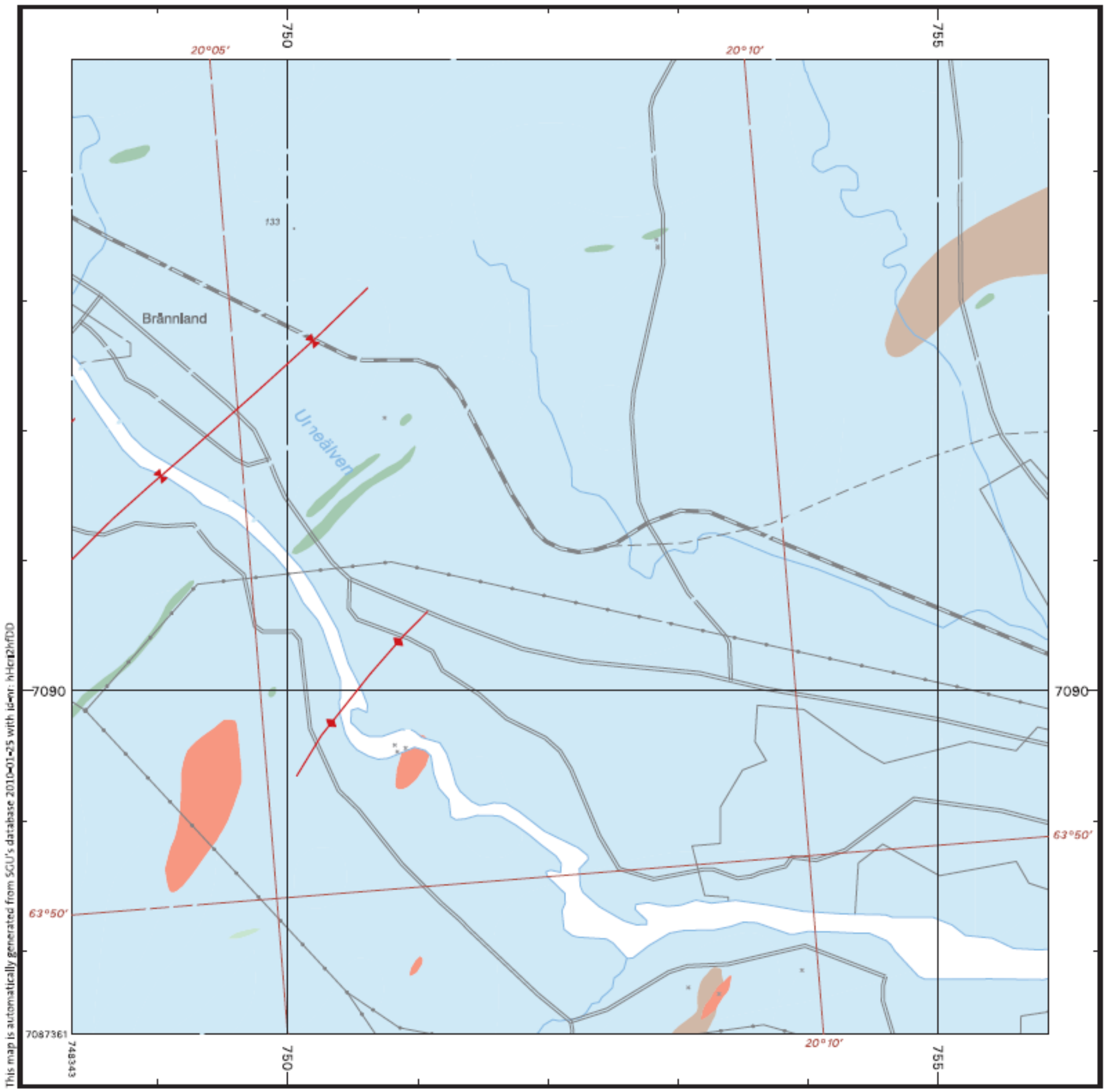
Zackrisson, O. (1977), Influence of forest fires on the North Swedish Boreal forest, *Oikos* **29**, 22-32.

Zahn, M.T., and Grimm, W.D. (1993), Nitrate and chloride loadings as anthropogenic indicators, *Water, Air, & Soil Pollution* **68**.3-4, 469 – 483.

Zheng, S.J. (2010), Crop production on acidic soils: overcoming aluminium toxicity and phosphorus deficiency, *Annals of Botany* **106**.1, 183 – 184.

Zorich, Z. (2008), Native Sweden, *Archaeology* **61**.4.

Appendix 1: Geology map for Prästsjödiket and Kåddis sites; ©Geological Survey of Sweden (2010)



The map shows a generalized view of the bedrock distribution. Observations of rock types and age relations are performed on outcrops. The composition of bedrock that is covered by unconsolidated sediments is interpreted from observations on nearby outcrops, geophysical measurements and, where applicable, from drill core analyses or diggings.

Areas too small to show on the map are represented as dots or line objects. Accuracy in the position is normally better than 50 m for observations. For interpreted phenomena, e.g. rock type boundaries, the accuracy may be much lower.

Additional information is stored in SGU's database, e.g. detailed information about mineralizations or the bedrock's mineral content, chemical composition, petrophysical characteristics or natural radioactive radiation, and can be ordered from SGU.

Synform

Antiform

Paleoproterozoic ca 1.87–1.75 Ga

Acid to intermediate intrusive rock (granite, granodiorite etc.)

Paleoproterozoic ca 1.96–1.86 Ga

Basic intrusive rock (gabbro, diorite etc.)

Acid to intermediate intrusive rock (granite, granodiorite etc.)

Sedimentary rock (sandstone, greywacke, clay shale etc.)

Basic volcanic rock (basalt etc.)

Proterozoic 2,5–0,54 Ga

Basic volcanic rock (basalt etc.)

Bedrock observations

Head Office:
Box 670
SE-751 28 Uppsala, Sweden
Tel: +46 (0) 18 17 90 00
E-mail: kundservice@sgu.se
www.sgu.se

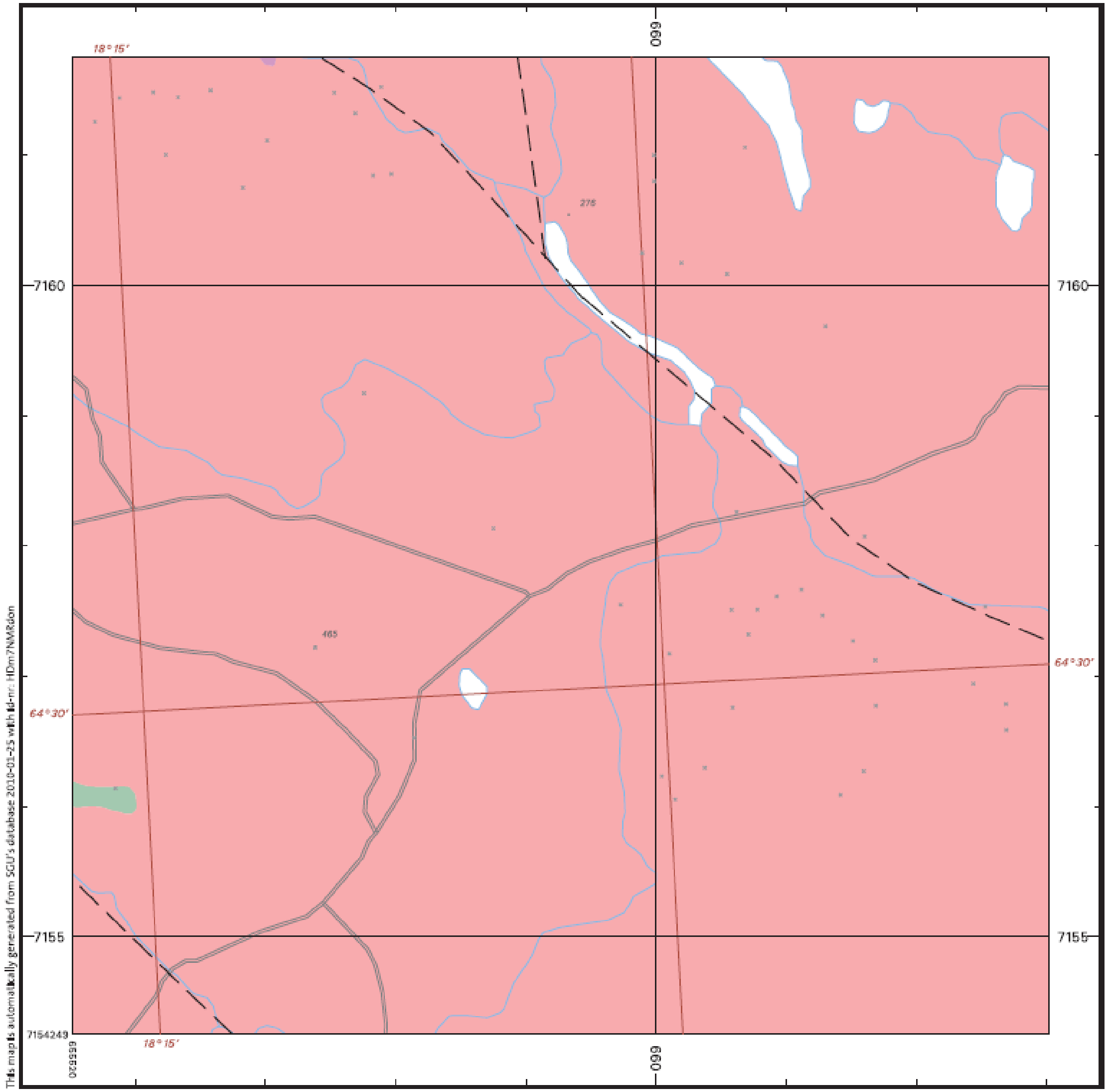
0 0.5 1.0 1.5 2.0 2.5 km

Scale 1:50 000

Topographic background: GSD-General Map
© Lantmäteriet. MS2009/08799

Grid in black shows coordinates in SWEREF 99 TM.
Grid in brown indicates latitude and longitude in the reference system SWEREF 99.

Appendix 2: Geology map for Lass Mass Heden; ©Geological Survey of Sweden (2010)



© Geological Survey of Sweden (SGU)

Head Office:
Box 670
SE-751 28 Uppsala, Sweden
Tel: +46 (0) 18 17 90 00
E-mail: kundservice@sgu.se
www.sgu.se

0 0.5 1.0 1.5 2.0 2.5 km

Scale 1:50 000

Topographic background: GSD-General Map
© Lantmäteriet. MS2009/08799

Grid in black shows coordinates in SWEREF 99 TM.
Grid in brown indicates latitude and longitude in the reference system SWEREF 99.

The map shows a generalized view of the bedrock distribution. Observations of rock types and age relations are performed on outcrops. The composition of bedrock that is covered by unconsolidated sediments is interpreted from observations on nearby outcrops, geophysical measurements and, where applicable, from drill core analyses or diggings.

Areas too small to show on the map are represented as dots or line objects. Accuracy in the position is normally better than 50 m for observations. For interpreted phenomena, e.g. rock type boundaries, the accuracy may be much lower.

Additional information is stored in SGU's database, e.g. detailed information about mineralizations or the bedrock's mineral content, chemical composition, petrophysical characteristics or natural radioactive radiation, and can be ordered from SGU.

Deformation zone, unspecified

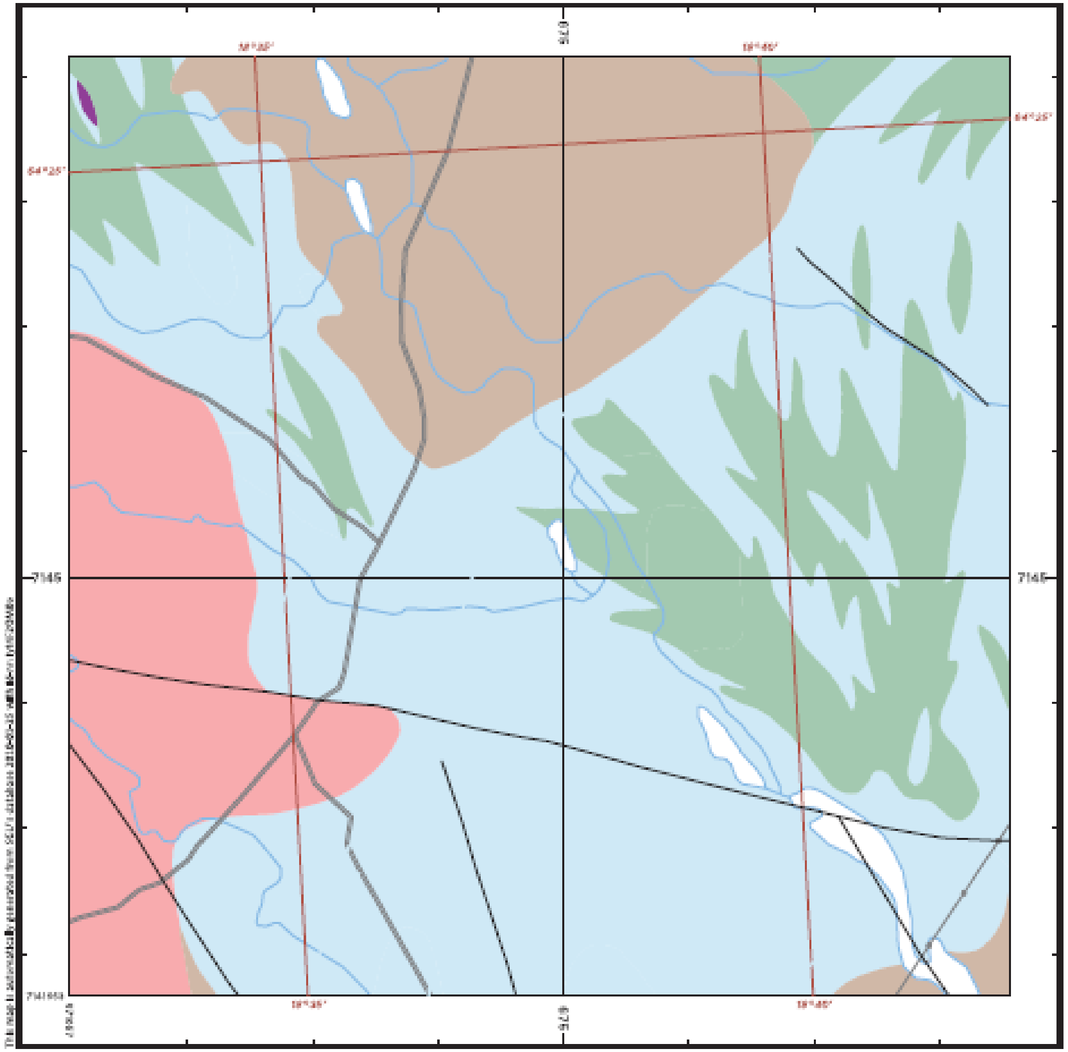
Mesoproterozoic 1,6–1,0 Ga
Diabase

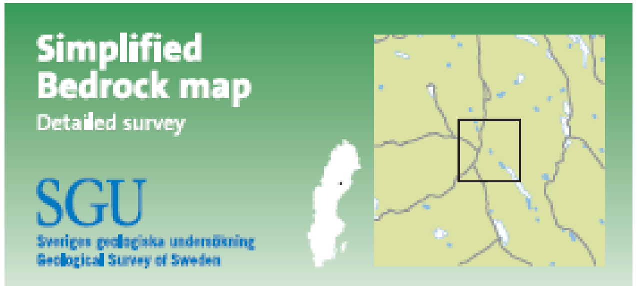
Paleoproterozoic ca 1.87–1.66 Ga
Acid to intermediate intrusive rock (granite, granodiorite etc.)

Paleoproterozoic ca 1.96–1.86 Ga
Basic volcanic rock (basalt etc.)

+ Bedrock observations

Appendix 3: Geology map for Tjärdal; ©Geological Survey of Sweden (2010)





The map shows a generalized view of the bedrock distribution. Observations of rock types and age relations are performed on outcrops. The composition of bedrock that is covered by unconsolidated sediments is interpreted from observations on nearby outcrops, geophysical measurements and, where applicable, from drill core analyses or diggings.

Areas too small to show on the map are represented as dots or line objects. Accuracy in the position is normally better than 50 m for observations. For interpreted phenomena, e.g. rock type boundaries, the accuracy may be much lower.

Additional information is stored in SGU's database, e.g. detailed information about mineralizations or the bedrock's mineral content, chemical composition, petrophysical characteristics or natural radioactive radiation, and can be ordered from SGU.

Brittle deformation zone (fault, fracture, fracture zone)

Paleoproterozoic ca 1.87–1.66 Ga

Acid to intermediate intrusive rock (granite, granodiorite etc.)

Paleoproterozoic ca 1.96–1.86 Ga

Basic volcanic rock (basalt etc.)

Sedimentary rock (sandstone, greywacke, clay shale etc.)

Acid to intermediate intrusive rock (granite, granodiorite etc.)

Proterozoic 2.5–0.54 Ga

Diabase

Head Office:
Box 670
SE-751 28 Uppsala, Sweden
Tel.: +46 (0) 18 17 90 00
E-mail: kundservice@sgu.se
www.sgu.se

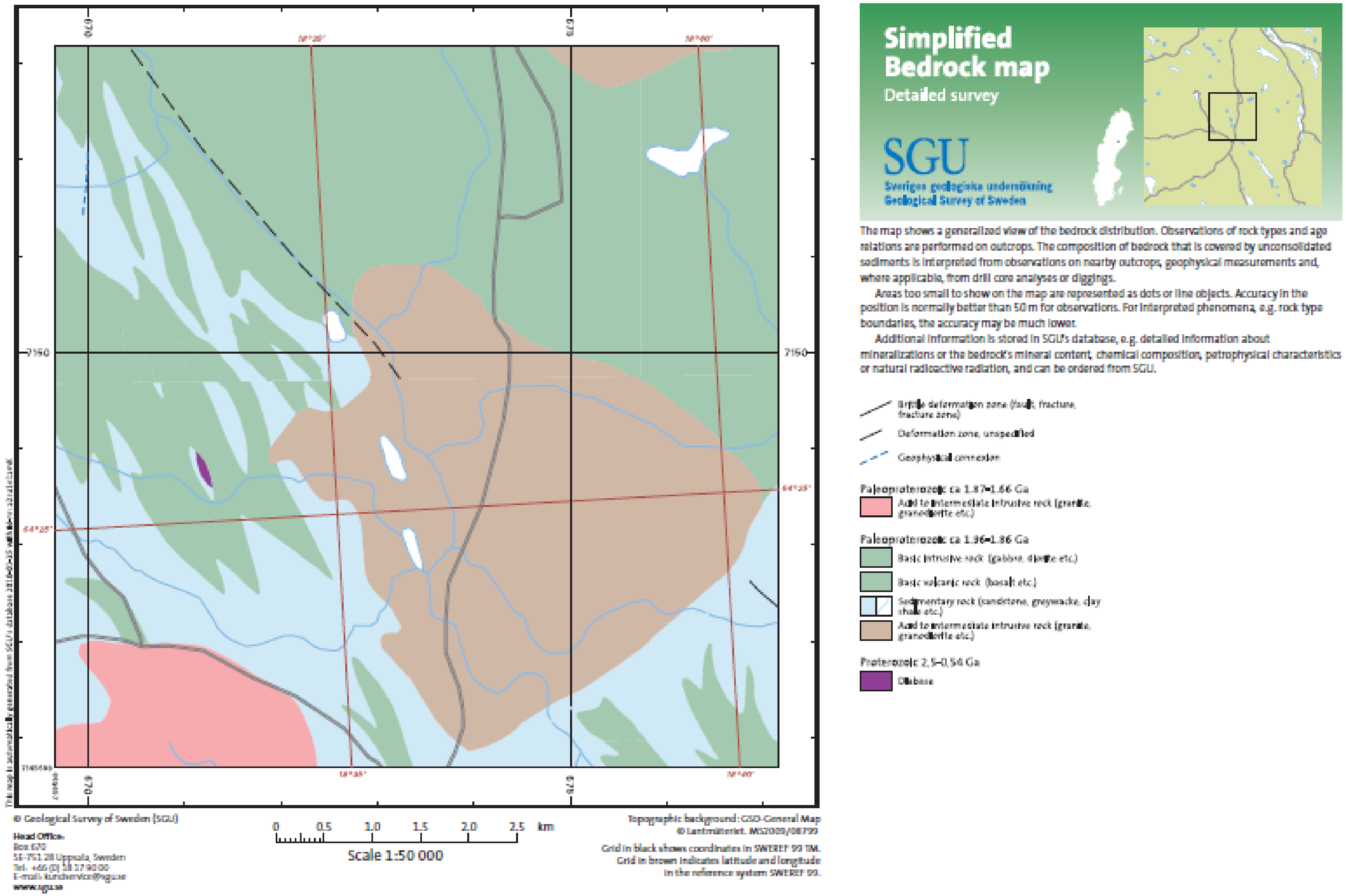
0 0.5 1.0 1.5 2.0 2.5 km

Scale 1:50 000

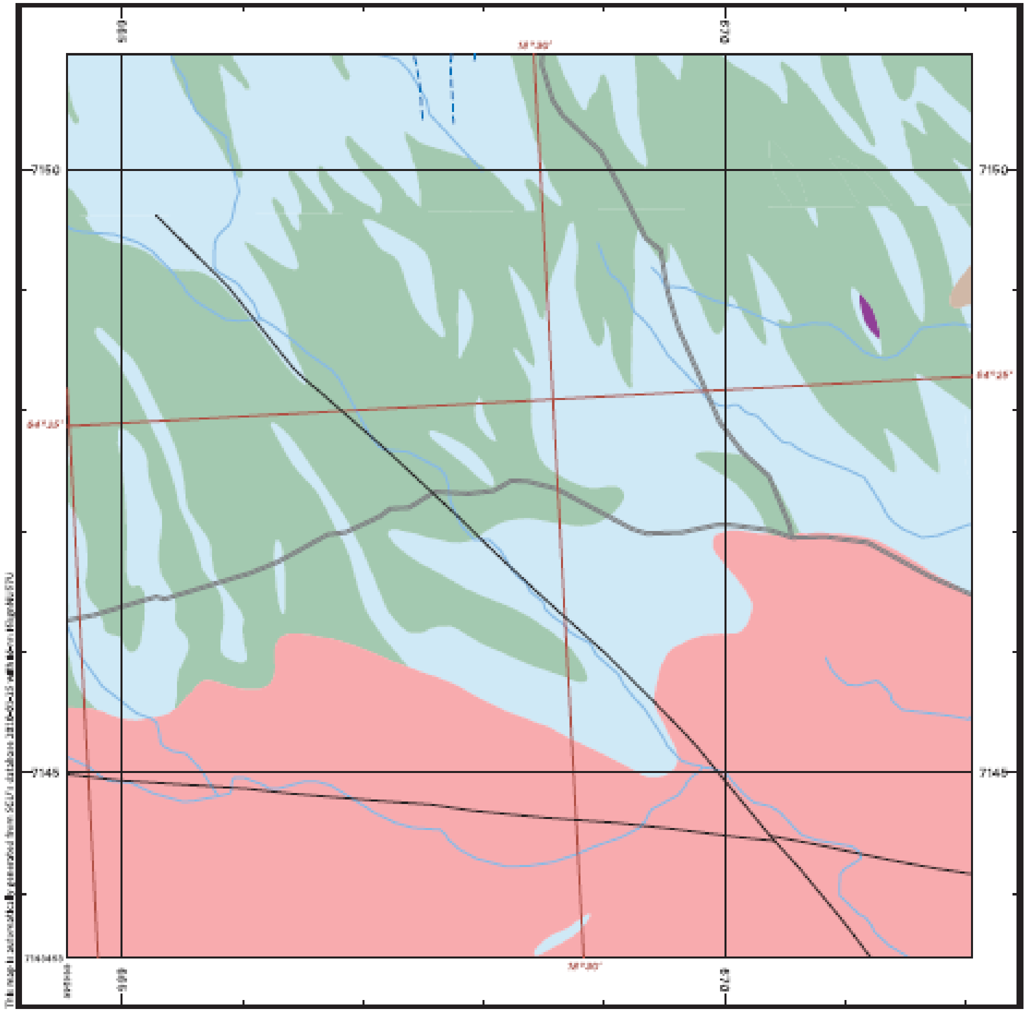
Topographic background: GSD-General Map
© Lantmäteriet. MS2009/08799

Grid in black shows coordinates in SWEREF 99 TM.
Grid in brown indicates latitude and longitude in the reference system SWEREF 99.

Appendix 4: Geology map for Gammelhemmet; ©Geological Survey of Sweden (2010)



Appendix 5: Geology map for Hornmyr; ©Geological Survey of Sweden (2010)



Head Office:
Box 670
SE-751 28 Uppsala, Sweden
Tel.: +46 (0) 18 17 90 00
E-mail: kundservice@sgu.se
www.sgu.se

0 0.5 1.0 1.5 2.0 2.5 km

Scale 1:50 000

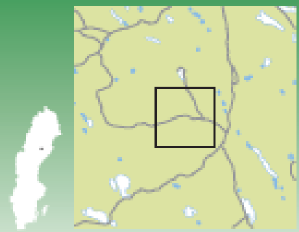
Topographic background: GSD-General Map
© Lantmäteriet. MS2009/08799

Grid in black shows coordinates in SWEREF 99 TM.
Grid in brown indicates latitude and longitude in the reference system SWEREF 99.

Simplified Bedrock map

Detailed survey

SGU
Sveriges geologiska undersökning
Geological Survey of Sweden



The map shows a generalized view of the bedrock distribution. Observations of rock types and age relations are performed on outcrops. The composition of bedrock that is covered by unconsolidated sediments is interpreted from observations on nearby outcrops, geophysical measurements and, where applicable, from drill core analyses or diggings.

Areas too small to show on the map are represented as dots or line objects. Accuracy in the position is normally better than 50 m for observations. For interpreted phenomena, e.g. rock type boundaries, the accuracy may be much lower.

Additional information is stored in SGU's database, e.g. detailed information about mineralizations or the bedrock's mineral content, chemical composition, petrophysical characteristics or natural radioactive radiation, and can be ordered from SGU.

- Brittle deformation zone (fault, fracture, fracture zone)
- Deformation zone, unspecified
- Geophysical connection

Paleoproterozoic ca 1.87–1.66 Ga
- Acid to intermediate intrusive rock (granite, granodiorite etc.)

Paleoproterozoic ca 1.96–1.86 Ga
- Basic intrusive rock (gabbro, diorite etc.)
- Basic volcanic rock (basalt etc.)
- Sedimentary rock (sandstone, greywacke, clay shale etc.)
- Acid to intermediate intrusive rock (granite, granodiorite etc.)

Proterozoic 2.5–0.54 Ga
- Diabase

Appendix 6: Micromorphological study of control reindeer faecal pellets

Name of site: Tjärdal
Location of site: Swedish Lapland, 22km south west of Lycksele
Site co-ordinates: N:64°23’25.2” E:018°37’50.3”

Reindeer faecal pellets were collected in June 2009 are were of an unknown age but as they appeared intact they would have been less than 6 months old; as if any older they would have been disturbed by winter weather. They remained in cold storage for 18 months before 3 were impregnated and manufactured into non-coverslipped thin section slides according to Murphy (1986) by G. MacLeod at the University of Stirling. Overall description carried out using Plane Polarised Light at a magnification of x2.

Diagnostic features:

- Undifferentiated b-fabric
- Close porphyric c/f distribution
- 20% void space with compound packing voids
- Virtually no mineral content (trace of quartz grains in slide, <20μm in size)
- Organic material is rough, fragmented and densely packed with mashing very dominant
- Organic material includes:
    - Tissue residue dominant
    - Frequent lignified tissue
    - Frequent parenchymatic tissue (see figure 2)
    - Polymorphic amorphous organic fine material (yellow, light brown, reddish brown & dark brown) common
    - Few cell residue
- Clusters of fungal hyphae
- Pedogenic organic iron features around edges of pellet

Key features:

- The pellets are rounded with undulating, weakly disintegrated boundaries. Edges appear darker in colour (dark brown) compared to inner material (light to yellowish brown) due to iron impregnation under PPL (see figure 1)
- Pellets are almost 100% organic with a mixture of tissues present, but dominantly tissue residue and lignified tissue, with a colour spectrum of yellows, reds and browns under PPL (see figure 1)
- Organic material will be rough, fragmented and mashed with parenchymatic tissue visible in XPL if sample is fresh (see figures 1+2)
- Clusters of fungal hyphae present but no fungal spores

Note: The organic constituents of reindeer faecal pellets will be largely made up from their ‘typical’ diets which in the summer comprises of willow and birch leaves, tundra grass and sedges and in the winter consists of lichens, moss and twigs. Therefore calcareous spherulites could be present in the faecal pellets of summer grazing reindeer provided that the soil conditions are not acidic (Canti, 1997; 1999).

Figure 1: Edge of reindeer faecal pellet in PPL, x1.25

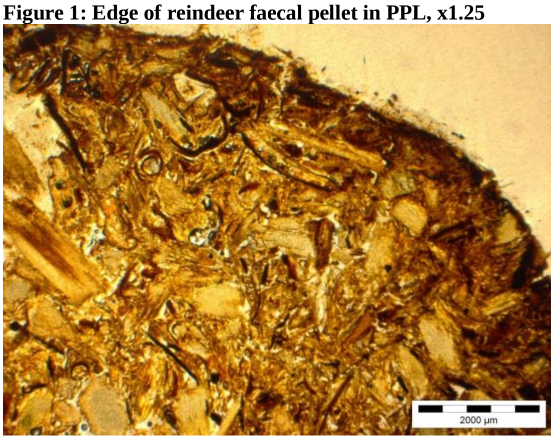
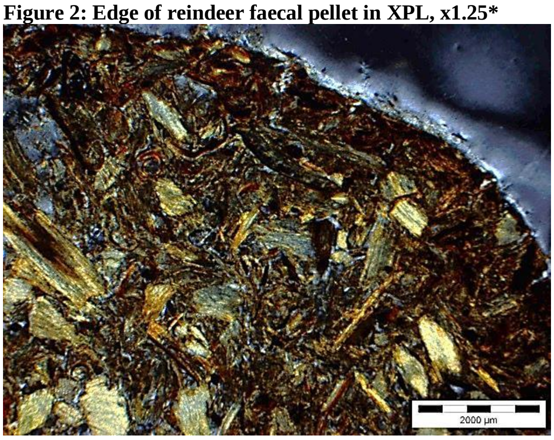


Figure 2: Edge of reindeer faecal pellet in XPL, x1.25*



**white shadows in XPL from production process & resin used*

Appendix 7: Magnetic susceptibility data tables for all sites

Site	Sample	Empty pot (g)	Full pot (g)	Weight of soil (g)	Pot volume cm^3	Bulk density	Air 1	Vol Suc LF (0.1)	Air 2	Corrected Vol Suc LF (0.1)	Vol Suc LF (1.0)
Prastsjodiket	1A	4.23	13.40	9.17	10	917	0.0	5.7	0.0	5.71	5
	1B	3.68	6.90	3.22	10	322	0.0	0.3	0.2	0.2	0
	1C	3.20	7.36	4.16	10	416	-0.1	0.3	0.3	0.25	0
	1D	4.22	7.10	2.88	10	288	-0.2	0.2	0.0	0.4	-1
	1E	4.32	7.14	2.82	10	282	0.0	0.0	0.1	-0.05	-1
	1F	4.35	11.14	6.79	10	679	0.0	1.6	0.4	1.4	1
	1G	4.10	13.74	9.64	10	964	0.0	6.0	0.0	6	5
	2A	4.30	13.16	8.86	10	886	-0.1	2.9	0.1	2.95	2
	2B	3.70	15.86	12.16	10	1216	0.1	7.5	0.3	7.25	7
	2C	3.20	17.38	14.18	10	1418	0.3	7.1	0.4	6.6	7
	2D	4.24	14.52	10.28	10	1028	0.4	6.9	0.7	6.15	7
	3A	4.24	11.04	6.8	10	680	-0.1	12.3	0.0	12.4	12
	3B	3.72	17.72	14	10	1400	0.0	9.2	0.0	9.2	9
	3C	3.22	18.84	15.62	10	1562	0.0	17.6	0.2	17.5	17
	3D	4.22	20.10	15.88	10	1588	0.2	34.4	0.4	34	34
	3E	4.32	20.14	15.82	10	1582	0.4	13.8	0.6	13.1	13
Lass Mass Heden	1A	4.26	13.66	9.4	10	940	-0.1	18.5	-0.1	18.65	18
	1B	3.74	15.16	11.42	10	1142	-0.1	19.0	-0.1	19.15	18
	1C	3.24	15.88	12.64	10	1264	-0.1	41.1	0.0	41.2	40
	1D	4.28	19.40	15.12	10	1512	0.0	53.3	0.0	53.3	53
	2A	4.26	10.44	6.18	10	618	-0.3	26.8	-0.2	27.2	26
	2B	3.74	15.80	12.06	10	1206	-0.2	37.0	-0.2	37.3	36
	2C	3.22	16.18	12.96	10	1296	-0.2	57.3	-0.1	57.55	56
	3A	4.24	8.40	4.16	10	416	-0.1	3.5	0.0	3.6	2
	4A	3.74	8.20	4.46	10	446	0.0	4.9	-0.1	4.95	5
	5A	4.24	11.66	7.42	10	742	-0.2	54.0	-0.1	54.25	4
	5B	3.74	15.76	12.02	10	1202	-0.1	7.0	0.1	7.05	6
	5C	3.22	15.98	12.76	10	1276	0.1	10.9	0.2	10.7	8
	5D	4.26	17.70	13.44	10	1344	0.2	15.7	0.2	15.4	14

Site	Sample	Vol Suc LF (1.0)	Vol Suc HF (1.0)	Frequency dependant susc	Mass Specific Dual Freq Dependant Suc	Mass specific Suc^{-8} (1.0)	**Mass specific Sus^{-8} (0.1)**
Prastsjodiket	1A	5	6	-20	-0.010905125	5.45	**6.23**
	1B	0	0	#DIV/0!	0	0.00	**0.62**
	1C	0	1	#DIV/0!	-0.024038462	0.00	**0.60**
	1D	-1	0	100	-0.034722222	-3.47	**1.39**
	1E	-1	0	100	-0.035460993	-3.55	**-0.18**
	1F	1	2	-100	-0.014727541	1.47	**2.06**
	1G	5	5	0	0	5.19	**6.22**
	2A	2	3	-50	-0.011286682	2.26	**3.33**
	2B	7	7	0	0	5.76	**5.96**
	2C	7	6	14.28571429	0.007052186	4.94	**4.65**
	2D	7	6	14.28571429	0.009727626	6.81	**5.98**
	3A	12	12	0	0	17.65	**18.24**
	3B	9	10	-11.11111111	-0.007142857	6.43	**6.57**
	3C	17	18	-5.882352941	-0.006402049	10.88	**11.20**
	3D	34	36	-5.882352941	-0.012594458	21.41	**21.41**
	3E	13	14	-7.692307692	-0.006321113	8.22	**8.28**
Lass Mass Heden	1A	18	18	0	0	19.15	**19.84**
	1B	18	20	-11.11111111	-0.017513135	15.76	**16.77**
	1C	40	40	0	0	31.65	**32.59**
	1D	53	54	-1.886792453	-0.006613757	35.05	**35.25**
	2A	26	26	0	0	42.07	**44.01**
	2B	36	37	-2.777777778	-0.008291874	29.85	**30.93**
	2C	56	58	-3.571428571	-0.015432099	43.21	**44.41**
	3A	2	3	-50	-0.024038462	4.81	**8.65**
	4A	5	5	0	0	11.21	**11.10**
	5A	4	5	-25	-0.013477089	5.39	**73.11**
	5B	6	6	0	0	4.99	**5.87**
	5C	8	9	-12.5	-0.007836991	6.27	**8.39**
	5D	14	16	-14.28571429	-0.014880952	10.42	**11.46**

Site	Sample	Empty pot (g)	Full pot (g)	Weight of soil (g)	Pot volume cm^3	Bulk density	Air 1	Vol Suc LF (0.1)	Air 2	Corrected Vol Suc LF (0.1)	Vol Suc LF (1.0)
Tjardal	1A	4.22	12.64	8.42	10	842	-0.1	40.9	-0.1	41.05	40
	1B	3.74	16.06	12.32	10	1232	-0.1	39.3	-0.1	39.45	39
	1C	3.22	14.26	11.04	10	1104	-0.1	76.2	-0.2	76.4	75
	1D	4.26	18.14	13.88	10	1388	-0.2	49.4	-0.1	49.65	48
	1E	4.32	19.64	15.32	10	1532	-0.1	33.2	-0.1	33.35	31
	2A	4.30	10.44	6.14	10	614	-0.1	14.3	0.1	14.35	12
	3A	4.24	8.24	4	10	400	-0.1	12.3	-0.1	12.45	11
	4A	3.72	9.00	5.28	10	528	-0.1	3.3	-0.1	3.45	3
	4B	3.22	11.36	8.14	10	814	-0.1	18.0	-0.1	18.15	17
	4C	4.26	14.02	9.76	10	976	-0.1	47.2	-0.1	47.35	46
	4D	4.32	15.54	11.22	10	1122	-0.1	7.1	0.0	7.2	6
	5A	4.30	6.84	2.54	10	254	0.0	4.2	-0.1	4.25	3
Hornmyr	1A	4.24	14.44	10.2	10	1020	0.0	22.4	-0.2	22.5	22
	1A*	4.10	15.18	11.08	10	1108	-0.2	26.4	-0.1	26.65	25
	1B	3.70	15.44	11.74	10	1174	-0.1	6.8	-0.1	6.95	5
	1C	3.20	14.84	11.64	10	1164	-0.1	12.5	-0.1	12.65	11
	1D	4.24	15.72	11.48	10	1148	-0.1	20.3	-0.1	20.45	19
	1E	4.32	18.80	14.48	10	1448	-0.1	34.2	-0.1	34.35	33
	2A	4.26	15.66	11.4	10	1140	-0.2	26.1	-0.1	26.35	24
	2B	3.72	14.80	11.08	10	1108	-0.1	32.3	0.0	32.4	29
	3A	3.22	15.10	11.88	10	1188	0.0	34.5	0.1	34.45	32
	4A	4.24	13.82	9.58	10	958	0.1	59.6	0.1	59.45	56
	4B	4.32	16.60	12.28	10	1228	0.1	9.6	-0.1	9.55	6
	4C	4.28	15.76	11.48	10	1148	-0.1	33.6	0.0	33.7	30
	5A	4.10	11.60	7.5	10	750	0.0	2.5	0.2	2.4	2
	6A	3.68	5.76	2.08	10	208	0.2	0.2	0.2	-0.1	-2

Site	Sample	Vol Suc LF (1.0)	Vol Suc HF (1.0)	Frequency dependant susc	Mass Specific Dual Freq Dependant Suc	Mass specific Suc^{-8} (1.0)	**Mass specific Sus^{-8} (0.1)**
Tjardal	1A	40	40	0	0	47.51	**48.75**
	1B	39	40	-2.564102564	-0.008116883	31.66	**32.02**
	1C	75	75	0	0	67.93	**69.20**
	1D	48	50	-4.166666667	-0.014409222	34.58	**35.77**
	1E	31	33	-6.451612903	-0.01305483	20.23	**21.77**
	2A	12	14	-16.66666667	-0.03257329	19.54	**23.37**
	3A	11	11	0	0	27.50	**31.13**
	4A	3	2	33.33333333	0.018939394	5.68	**6.53**
	4B	17	17	0	0	20.88	**22.30**
	4C	46	44	4.347826087	0.020491803	47.13	**48.51**
	4D	6	6	0	0	5.35	**6.42**
	5A	3	3	0	0	11.81	**16.73**
Hornmyr	1A	22	22	0	0	21.57	**22.06**
	1A*	25	26	-4	-0.009025271	22.56	**24.05**
	1B	5	7	-40	-0.017035775	4.26	**5.92**
	1C	11	12	-9.090909091	-0.008591065	9.45	**10.87**
	1D	19	20	-5.263157895	-0.008710801	16.55	**17.81**
	1E	33	34	-3.03030303	-0.006906077	22.79	**23.72**
	2A	24	26	-8.333333333	-0.01754386	21.05	**23.11**
	2B	29	31	-6.896551724	-0.018050542	26.17	**29.24**
	3A	32	34	-6.25	-0.016835017	26.94	**29.00**
	4A	56	40	28.57142857	0.167014614	58.46	**62.06**
	4B	6	10	-66.66666667	-0.03257329	4.89	**7.78**
	4C	30	33	-10	-0.026132404	26.13	**29.36**
	5A	2	2	0	0	2.67	**3.20**
	6A	-2	0	100	-0.096153846	-9.62	**-0.48**

Site	Sample	Empty pot (g)	Full pot (g)	Weight of soil (g)	Pot volume cm^3	Bulk density	Air 1	Vol Suc LF (0.1)	Air 2	Corrected Vol Suc LF (0.1)	Vol Suc LF (1.0)
Gammelhemmet	1A	4.24	16.20	11.96	10	1196	-0.1	31.1	-0.2	31.3	29
	1B	3.70	16.96	13.26	10	1326	-0.2	26.1	0.0	26.3	23
	1C	3.22	18.68	15.46	10	1546	0.0	48.2	0.0	48.2	53
	1D	4.26	20.10	15.84	10	1584	0.0	58.9	0.0	58.9	63
	2A	4.34	15.22	10.88	10	1088	0.0	32.4	0.2	32.3	37
	3A	4.24	10.16	5.92	10	592	-0.1	8.8	0.0	8.9	7
	3B	3.72	14.96	11.24	10	1124	0.0	15.1	0.0	15.1	14
	3C	3.22	16.24	13.02	10	1302	0.0	20.9	0.1	20.85	19
	3D	4.26	18.62	14.36	10	1436	0.1	27.7	0.4	27.4	26
	3E	4.34	17.78	13.44	10	1344	0.4	22.6	0.4	22	20
	4A	4.30	14.50	10.2	10	1020	0.4	38.0	0.6	37.3	36
	5A	4.10	15.44	11.34	10	1134	0.6	40.0	0.7	39.05	38
Kaddis	1A	4.24	15.74	11.5	10	1150	-0.1	4.1	-0.1	4.25	3
	1B	3.72	17.62	13.9	10	1390	-0.1	5.5	0.0	5.6	4
	1C	3.20	17.34	14.14	10	1414	0.0	8.6	0.0	8.6	7
	2A	4.24	18.72	14.48	10	1448	0.0	5.7	0.1	5.65	4
	3A	4.34	17.98	13.64	10	1364	0.1	7.4	0.2	7.2	6
	4A	4.24	9.54	5.3	10	530	-0.1	4.3	-0.2	4.5	3
	4B	3.72	17.00	13.28	10	1328	-0.2	5.9	-0.1	6.15	5
	4C	3.20	18.64	15.44	10	1544	-0.1	18.7	0.1	18.75	16
	4D	4.26	19.20	14.94	10	1494	0.1	0.2	12.9	-6.35	10
	5A	4.34	8.96	4.62	10	462	0.2	1.2	0.1	0.95	0

Site	Sample	Vol Suc LF (1.0)	Vol Suc HF (1.0)	Frequency dependant susc	Mass Specific Dual Freq Dependant Suc	Mass specific Suc^{-8} (1.0)	**Mass specific Sus^{-8} (0.1)**
Gammelhemmet	1A	29	31	-6.896551724	-0.016722408	24.25	**26.17**
	1B	23	27	-17.39130435	-0.030165913	17.35	**19.83**
	1C	53	49	7.547169811	0.025873221	34.28	**31.18**
	1D	63	59	6.349206349	0.025252525	39.77	**37.18**
	2A	37	32	13.51351351	0.045955882	34.01	**29.69**
	3A	7	8	-14.28571429	-0.016891892	11.82	**15.03**
	3B	14	15	-7.142857143	-0.008896797	12.46	**13.43**
	3C	19	20	-5.263157895	-0.007680492	14.59	**16.01**
	3D	26	26	0	0	18.11	**19.08**
	3E	20	22	-10	-0.014880952	14.88	**16.37**
	4A	36	37	-2.777777778	-0.009803922	35.29	**36.57**
	5A	38	38	0	0	33.51	**34.44**
Kaddis	1A	3	4	-33.33333333	-0.008695652	2.61	**3.70**
	1B	4	7	-75	-0.021582734	2.88	**4.03**
	1C	7	9	-28.57142857	-0.014144272	4.95	**6.08**
	2A	4	7	-75	-0.020718232	2.76	**3.90**
	3A	6	8	-33.33333333	-0.014662757	4.40	**5.28**
	4A	3	4	-33.33333333	-0.018867925	5.66	**8.49**
	4B	5	5	0	0	3.77	**4.63**
	4C	16	18	-12.5	-0.012953368	10.36	**12.14**
	4D	10	12	-20	-0.013386881	6.69	**-4.25**
	5A	0	1	0	-0.021645022	0.00	**2.06**

Appendix 8: Normality tests and accompanying residual plots for each element

General Linear Model: Na versus Set

Factor	Type	Levels	Values
Set	fixed	4	1, 2, 3, 4

Analysis of Variance for Na, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Set	3	0.76906	0.76906	0.25635	4.61	**0.004**
Error	136	7.55619	7.55619	0.05556		
Total	139	8.32525				

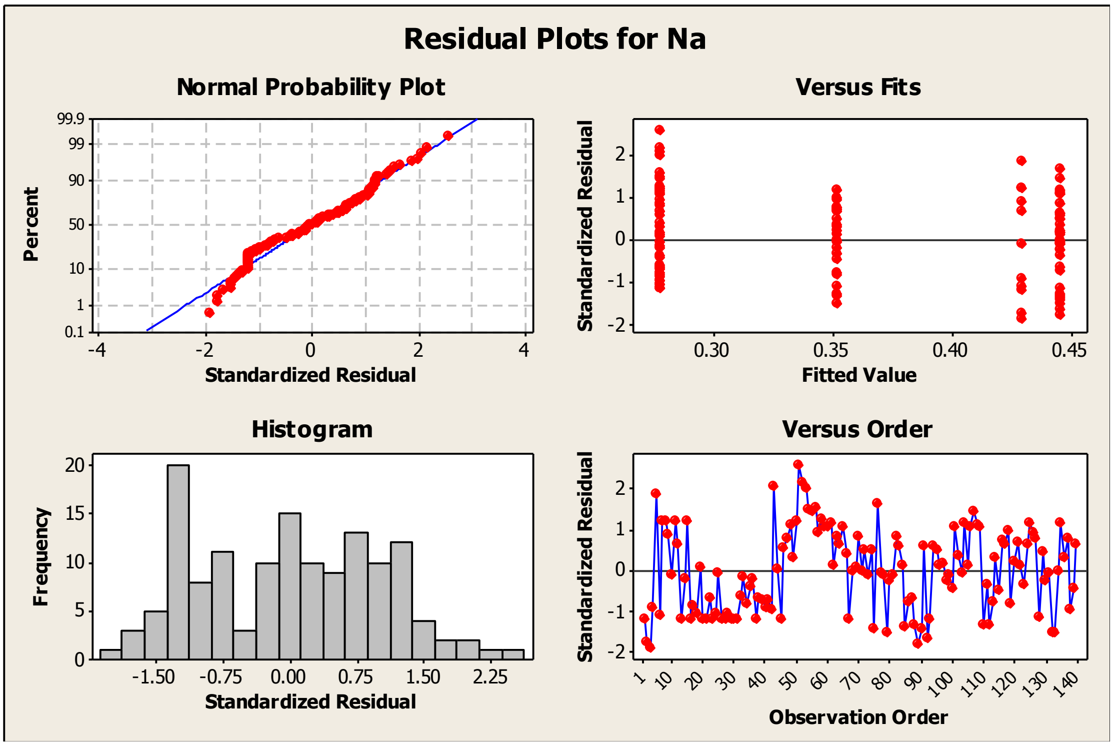
S = 0.235712   R-Sq = 9.24%   R-Sq(adj) = 7.24%

Unusual Observations for Na

Obs	Na	Fit	SE Fit	Residual	St Resid	
43	0.760000	0.276724	0.030951	0.483276	2.07	R
51	0.880000	0.276724	0.030951	0.603276	2.58	R
52	0.780000	0.276724	0.030951	0.503276	2.15	R

R denotes an observation with a large standardized residual.

Residual Plots for Na

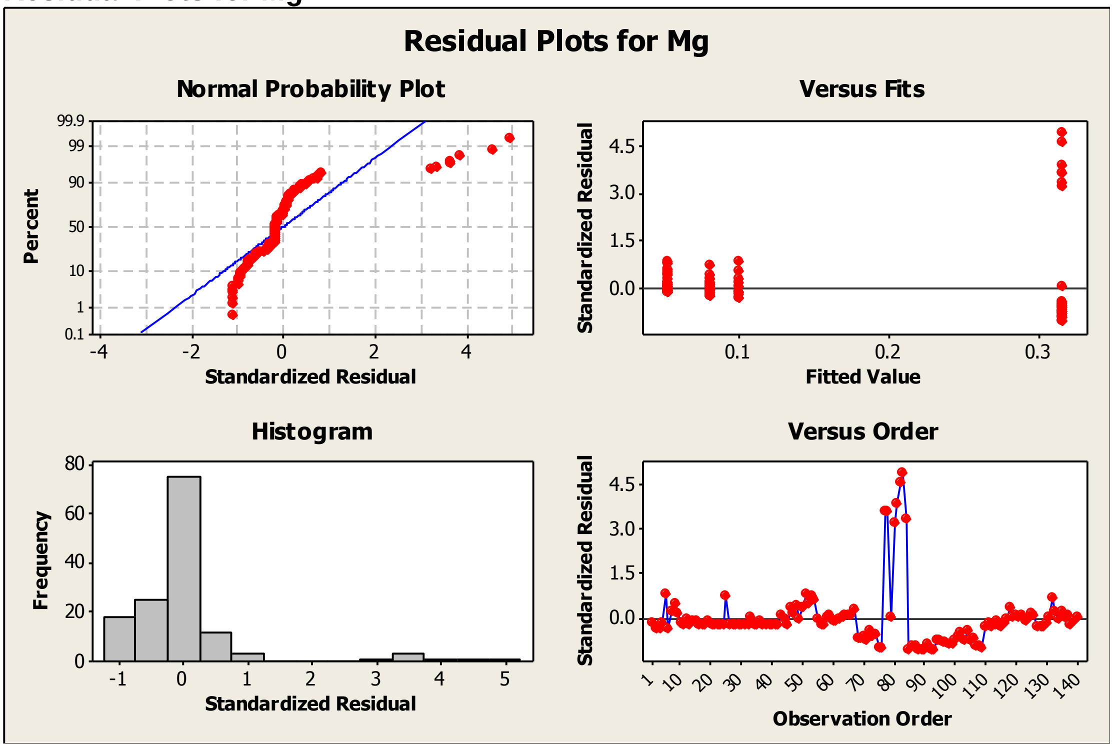


Na = normally distributed

General Linear Model: Mg versus Set

```
Factor  Type   Levels  Values
Set     fixed       4  1, 2, 3, 4


Analysis of Variance for Mg, using Adjusted SS for Tests

Source   DF    Seq SS    Adj SS   Adj MS     F      P
Set       3   1.85909   1.85909  0.61970  7.08  0.000
Error   136  11.89736  11.89736  0.08748
Total   139  13.75644


S = 0.295771   R-Sq = 13.51%   R-Sq(adj) = 11.61%


Unusual Observations for Mg

Obs       Mg      Fit   SE Fit  Residual  St Resid
 77  1.38000  0.31595  0.04564   1.06405      3.64 R
 78  1.38000  0.31595  0.04564   1.06405      3.64 R
 80  1.26000  0.31595  0.04564   0.94405      3.23 R
 81  1.45000  0.31595  0.04564   1.13405      3.88 R
 82  1.66000  0.31595  0.04564   1.34405      4.60 R
 83  1.76000  0.31595  0.04564   1.44405      4.94 R
 84  1.30000  0.31595  0.04564   0.98405      3.37 R

R denotes an observation with a large standardized residual.
```

Residual Plots for Mg

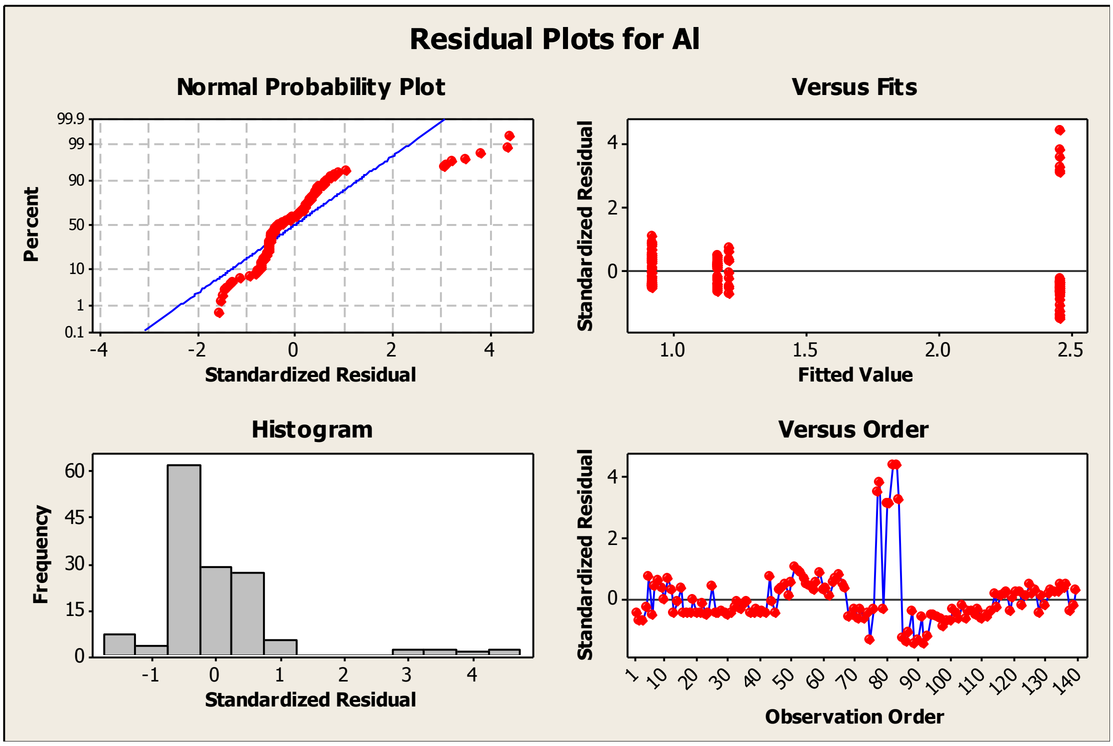


Mg= normally distributed with exception of group 4 (control)

General Linear Model: Al versus Set

```
Factor  Type   Levels  Values
Set     fixed       4  1, 2, 3, 4


Analysis of Variance for Al, using Adjusted SS for Tests

Source   DF   Seq SS   Adj SS  Adj MS     F      P
Set       3   62.722   62.722  20.907  9.40  0.000
Error   136  302.432  302.432   2.224
Total   139  365.153


S = 1.49123   R-Sq = 17.18%   R-Sq(adj) = 15.35%


Unusual Observations for Al

Obs        Al      Fit   SE Fit  Residual  St Resid
 77  7.66000  2.46095  0.23010   5.19905      3.53 R
 78  8.09000  2.46095  0.23010   5.62905      3.82 R
 80  7.08000  2.46095  0.23010   4.61905      3.14 R
 81  7.03000  2.46095  0.23010   4.56905      3.10 R
 82  8.93000  2.46095  0.23010   6.46905      4.39 R
 83  8.96000  2.46095  0.23010   6.49905      4.41 R
 84  7.25000  2.46095  0.23010   4.78905      3.25 R

R denotes an observation with a large standardized residual.
```

Residual Plots for Al

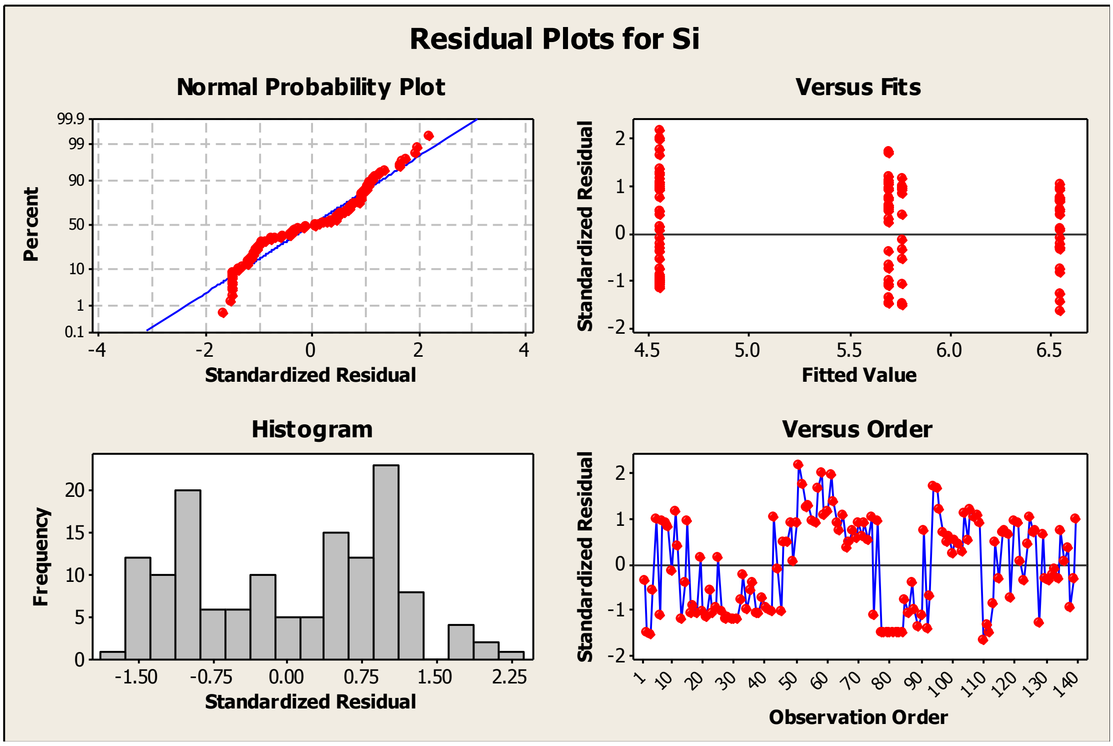


Al = normally distributed with exception of group 4 (control)

General Linear Model: Si versus Set

```
Factor  Type    Levels  Values
Set     fixed        4  1, 2, 3, 4


Analysis of Variance for Si, using Adjusted SS for Tests

Source   DF    Seq SS    Adj SS  Adj MS     F      P
Set       3     84.27     84.27   28.09  1.90  0.132
Error   136   2005.59   2005.59   14.75
Total   139   2089.86


S = 3.84018   R-Sq = 4.03%   R-Sq(adj) = 1.92%


Unusual Observations for Si

Obs       Si      Fit  SE Fit  Residual  St Resid
 51  12.9200   4.5512  0.5042    8.3688      2.20 R
 58  12.1900   4.5512  0.5042    7.6388      2.01 R

R denotes an observation with a large standardized residual.
```

Residual Plots for Si

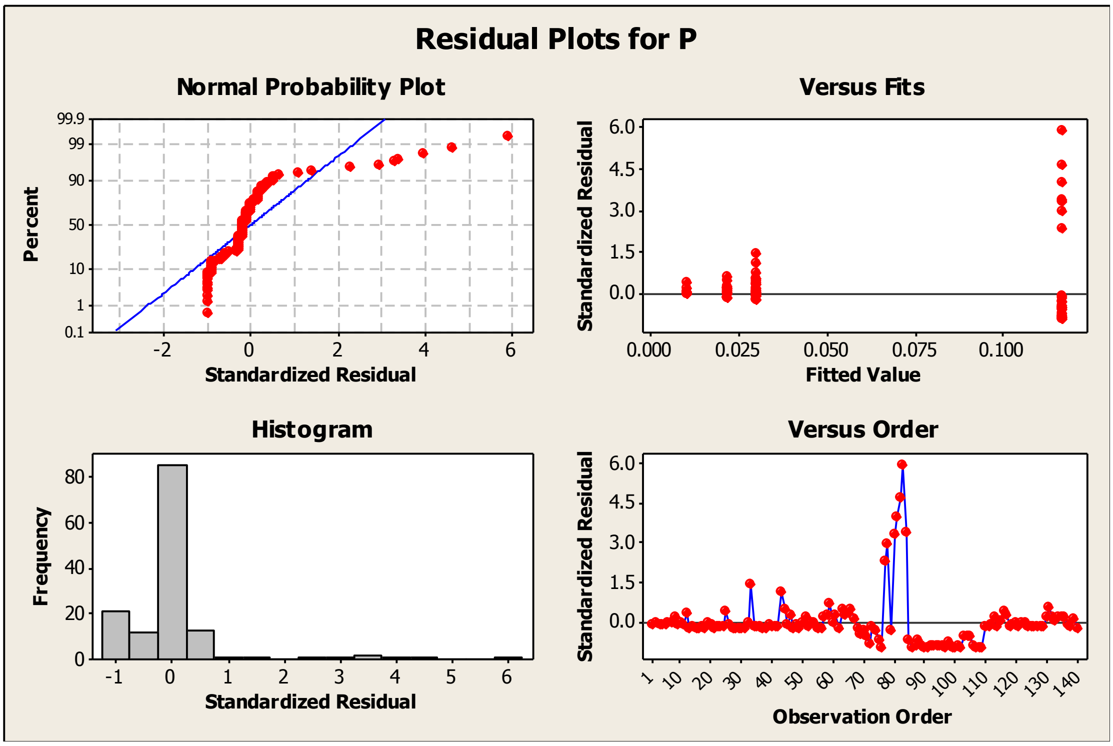


Si = normally distributed

General Linear Model: P versus Set

```
Factor  Type   Levels  Values
Set     fixed       4  1, 2, 3, 4


Analysis of Variance for P, using Adjusted SS for Tests

Source   DF   Seq SS   Adj SS   Adj MS     F      P
Set       3  0.25448  0.25448  0.08483  5.87  0.001
Error   136  1.96619  1.96619  0.01446
Total   139  2.22067


S = 0.120239   R-Sq = 11.46%   R-Sq(adj) = 9.51%


Unusual Observations for P

Obs         P       Fit    SE Fit  Residual  St Resid
 77  0.390000  0.117143  0.018553  0.272857      2.30 R
 78  0.470000  0.117143  0.018553  0.352857      2.97 R
 80  0.510000  0.117143  0.018553  0.392857      3.31 R
 81  0.590000  0.117143  0.018553  0.472857      3.98 R
 82  0.670000  0.117143  0.018553  0.552857      4.65 R
 83  0.820000  0.117143  0.018553  0.702857      5.92 R
 84  0.520000  0.117143  0.018553  0.402857      3.39 R

R denotes an observation with a large standardized residual.
```

Residual Plots for P

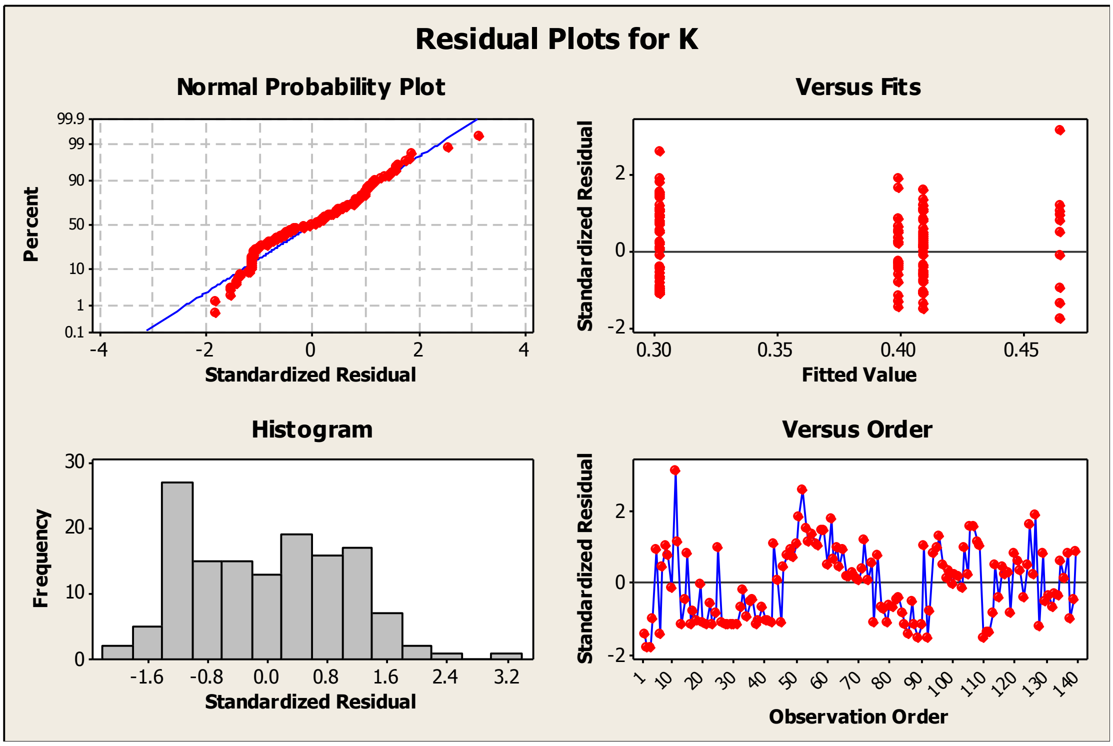


P = normally distributed with exception of group 4 (control)

General Linear Model: K versus Set

```
Factor  Type   Levels  Values
Set     fixed       4  1, 2, 3, 4


Analysis of Variance for K, using Adjusted SS for Tests

Source   DF    Seq SS   Adj SS   Adj MS     F      P
Set       3   0.47055  0.47055  0.15685  2.15  0.097
Error   136   9.92223  9.92223  0.07296
Total   139  10.39277


S = 0.270107   R-Sq = 4.53%   R-Sq(adj) = 2.42%


Unusual Observations for K

Obs        K      Fit   SE Fit  Residual  St Resid
 11  1.28000  0.46583  0.07797   0.81417    3.15 R
 52  0.99000  0.30155  0.03547   0.68845    2.57 R

R denotes an observation with a large standardized residual.
```

Residual Plots for K

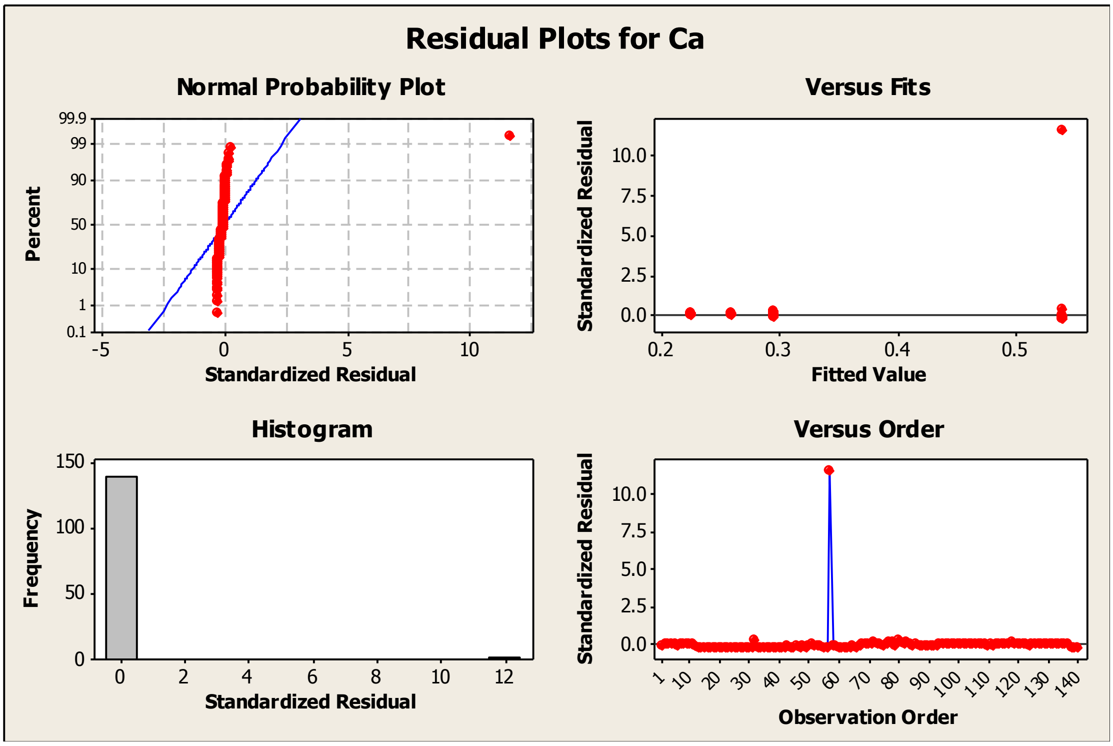


K = normally distributed

General Linear Model: Ca versus Set

```
Factor  Type   Levels  Values
Set     fixed       4  1, 2, 3, 4


Analysis of Variance for Ca, using Adjusted SS for Tests

Source   DF   Seq SS   Adj SS  Adj MS     F      P
Set       3    2.652    2.652   0.884  0.31  0.818
Error   136  387.404  387.404   2.849
Total   139  390.055


S = 1.68777   R-Sq = 0.68%   R-Sq(adj) = 0.00%


Unusual Observations for Ca

Obs       Ca     Fit  SE Fit  Residual  St Resid
 57  20.0000  0.5405  0.2216   19.4595     11.63 R

R denotes an observation with a large standardized residual.
```

Residual Plots for Ca

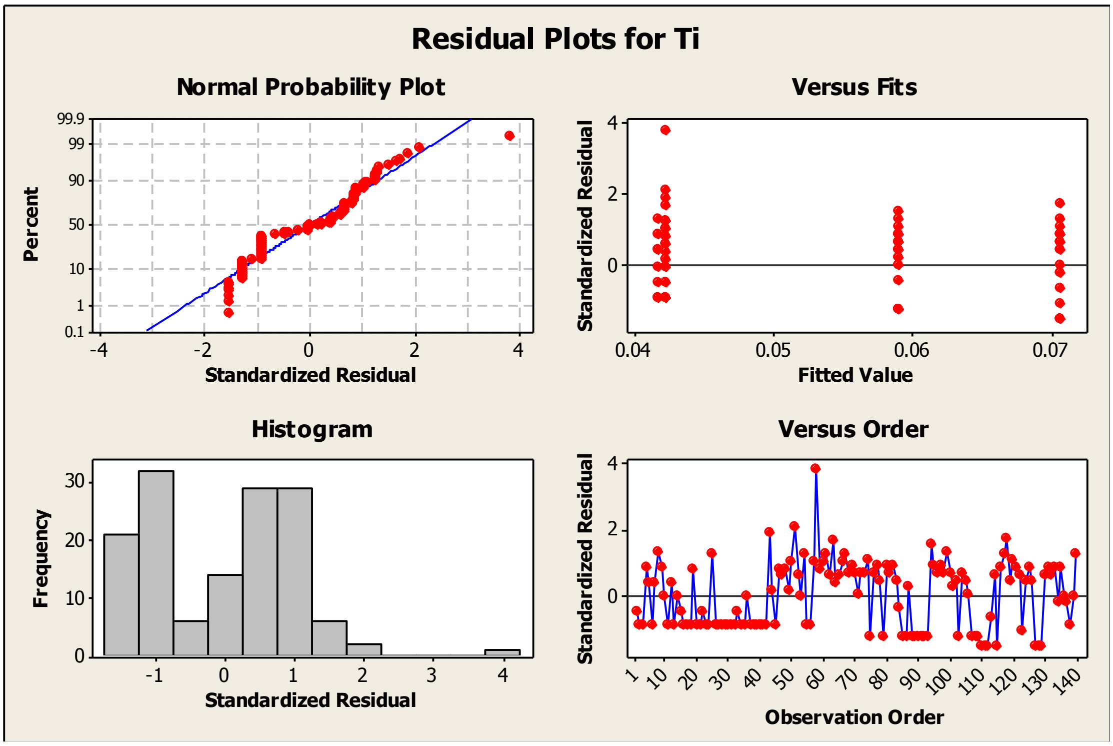


Ca = normally distributed with exception of group 4 (control)

General Linear Model: Ti versus Set

```
Factor  Type   Levels  Values
Set     fixed       4  1, 2, 3, 4


Analysis of Variance for Ti, using Adjusted SS for Tests

Source   DF    Seq SS    Adj SS    Adj MS     F      P
Set       3  0.018576  0.018576  0.006192  2.79  0.043
Error   136  0.301323  0.301323  0.002216
Total   139  0.319899


S = 0.0470703   R-Sq = 5.81%   R-Sq(adj) = 3.73%


Unusual Observations for Ti

Obs        Ti       Fit    SE Fit  Residual  St Resid
 51  0.140000  0.042241  0.006181  0.097759      2.10 R
 58  0.220000  0.042241  0.006181  0.177759      3.81 R

R denotes an observation with a large standardized residual.
```

Residual Plots for Ti

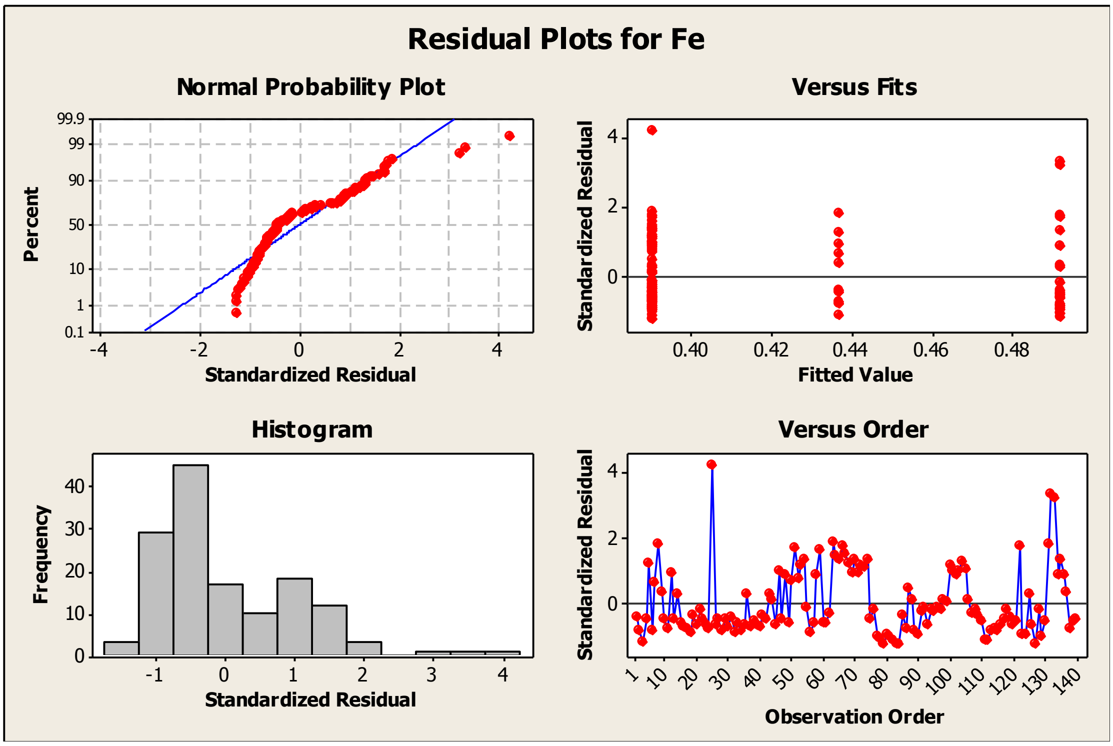


Ti = normally distributed

General Linear Model: Fe versus Set

```
Factor  Type   Levels  Values
Set     fixed       4  1, 2, 3, 4


Analysis of Variance for Fe, using Adjusted SS for Tests

Source   DF    Seq SS    Adj SS   Adj MS     F      P
Set       3   0.23423   0.23423  0.07808  0.80  0.498
Error   136  13.32764  13.32764  0.09800
Total   139  13.56186


S = 0.313045   R-Sq = 1.73%   R-Sq(adj) = 0.00%


Unusual Observations for Fe

Obs       Fe      Fit    SE Fit  Residual  St Resid
 25  1.70000  0.39017  0.04110   1.30983      4.22 R
132  1.52000  0.49214  0.05916   1.02786      3.34 R
133  1.48000  0.49214  0.05916   0.98786      3.21 R

R denotes an observation with a large standardized residual.
```

Residual Plots for Fe



Fe = normally distributed with exception of group 4 (control)

General Linear Model: Cl versus Set

Factor	Type	Levels	Values
Set	fixed	4	1, 2, 3, 4

Analysis of Variance for Cl, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Set	3	0.022637	0.022637	0.007546	5.04	**0.002**
Error	136	0.203577	0.203577	0.001497		
Total	139	0.226214				

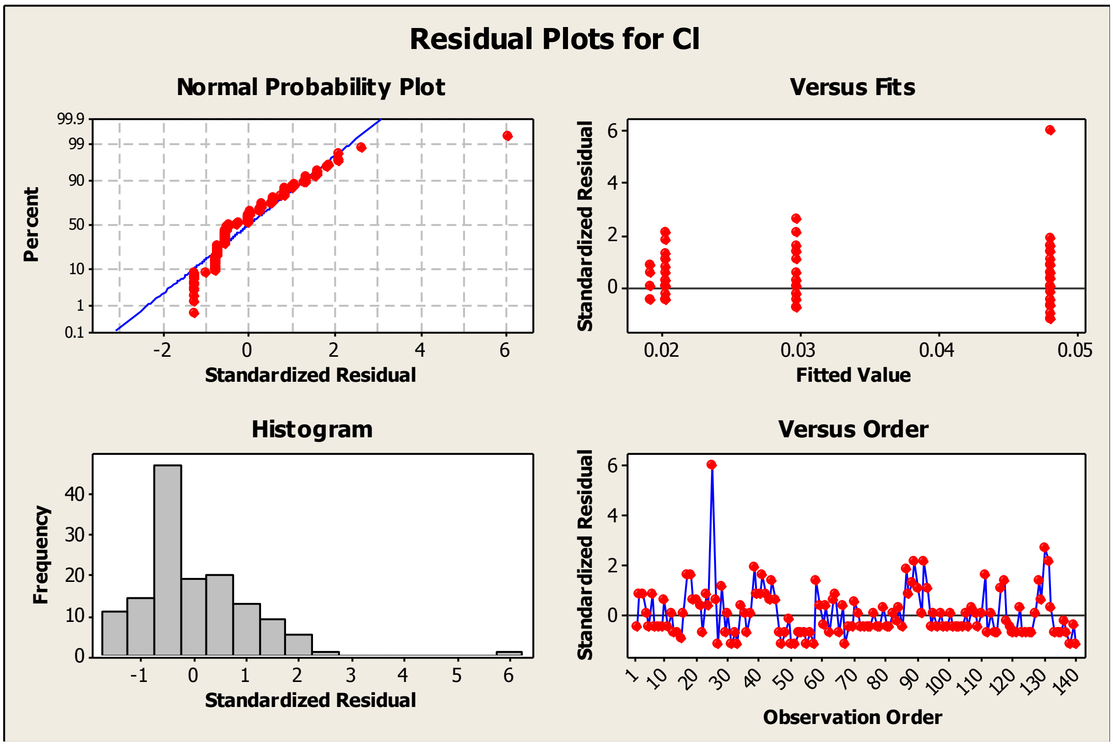
S = 0.0386897   R-Sq = 10.01%   R-Sq(adj) = 8.02%

Unusual Observations for Cl

Obs	Cl	Fit	SE Fit	Residual	St Resid
25	0.280000	0.048103	0.005080	0.231897	6.05 R
89	0.100000	0.020238	0.005970	0.079762	2.09 R
92	0.100000	0.020238	0.005970	0.079762	2.09 R
130	0.130000	0.029643	0.007312	0.100357	2.64 R
131	0.110000	0.029643	0.007312	0.080357	2.12 R

R denotes an observation with a large standardized residual.

Residual Plots for Cl



Cl = normally distributed with exception of group 4 (control) which has an outlier

General Linear Model: Mn versus Set

Factor	Type	Levels	Values
Set	fixed	4	1, 2, 3, 4

Analysis of Variance for Mn, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Set	3	0.0000067	0.0000067	0.0000022	0.77	0.510
Error	136	0.0003905	0.0003905	0.0000029		
Total	139	0.0003971				

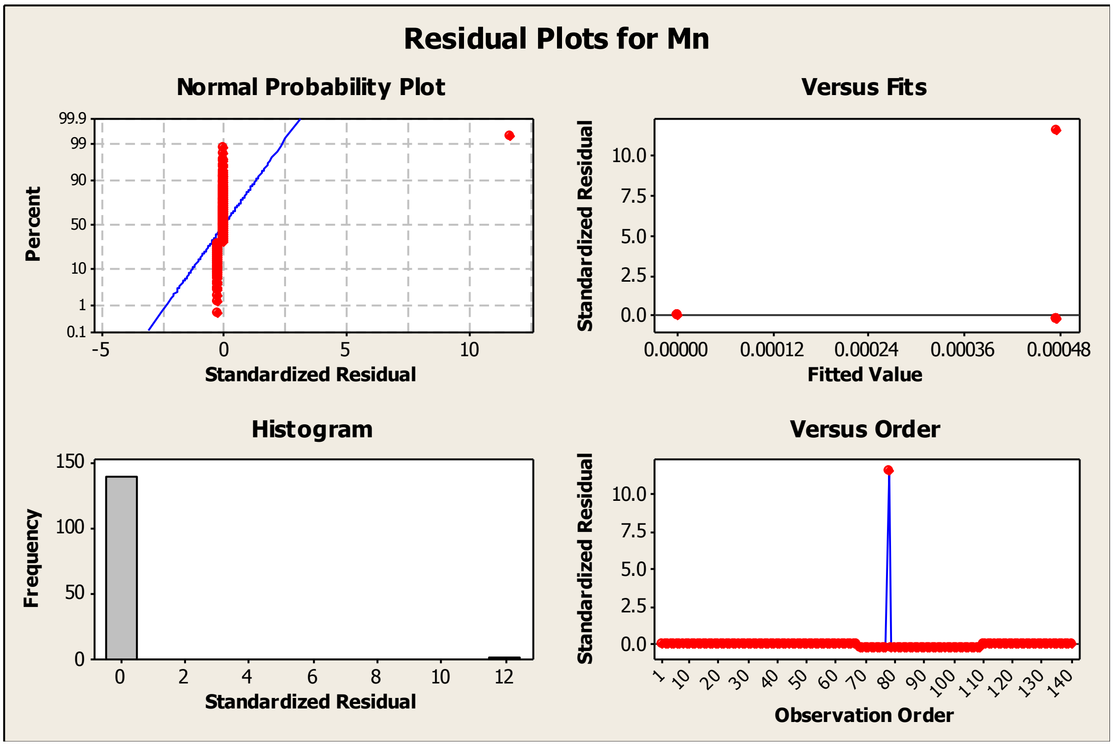
S = 0.00169445   R-Sq = 1.68%   R-Sq(adj) = 0.00%

Unusual Observations for Mn

Obs	Mn	Fit	SE Fit	Residual	St Resid
78	0.020000	0.000476	0.000261	0.019524	11.66 R

R denotes an observation with a large standardized residual.

Residual Plots for Mn

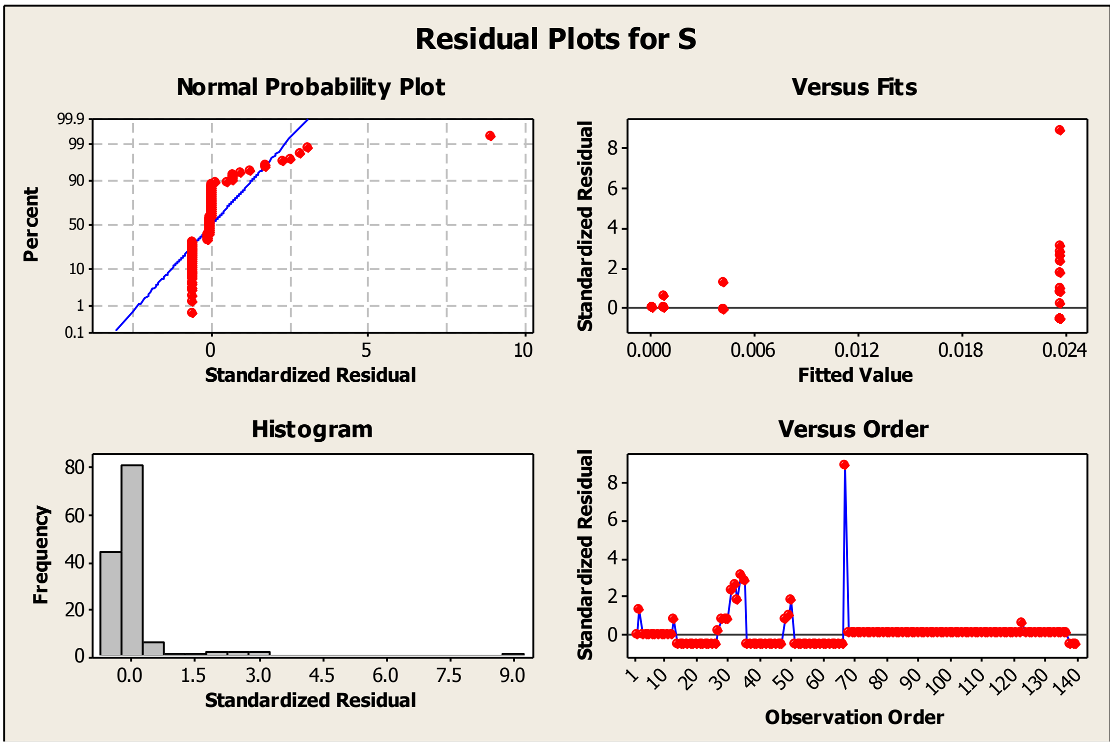


Mn = NOT normally distributed - ***too few samples***

General Linear Model: S versus Set

```
Factor  Type   Levels  Values
Set     fixed       4  1, 2, 3, 4


Analysis of Variance for S, using Adjusted SS for Tests

Source   DF    Seq SS    Adj SS    Adj MS     F      P
Set       3  0.018039  0.018039  0.006013  4.18  0.007
Error   136  0.195643  0.195643  0.001439
Total   139  0.213682


S = 0.0379282   R-Sq = 8.44%   R-Sq(adj) = 6.42%


Unusual Observations for S

Obs         S       Fit    SE Fit  Residual  St Resid
 31  0.110000  0.023793  0.004980  0.086207      2.29 R
 32  0.120000  0.023793  0.004980  0.096207      2.56 R
 34  0.140000  0.023793  0.004980  0.116207      3.09 R
 35  0.130000  0.023793  0.004980  0.106207      2.82 R
 67  0.360000  0.023793  0.004980  0.336207      8.94 R

R denotes an observation with a large standardized residual.
```

Residual Plots for S



S = NOT normally distributed - ***too few samples***

General Linear Model: Ni versus Set

Factor	Type	Levels	Values
Set	fixed	4	1, 2, 3, 4

Analysis of Variance for Ni, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Set	3	0.0001222	0.0001222	0.0000407	1.42	0.239
Error	136	0.0038914	0.0038914	0.0000286		
Total	139	0.0040136				

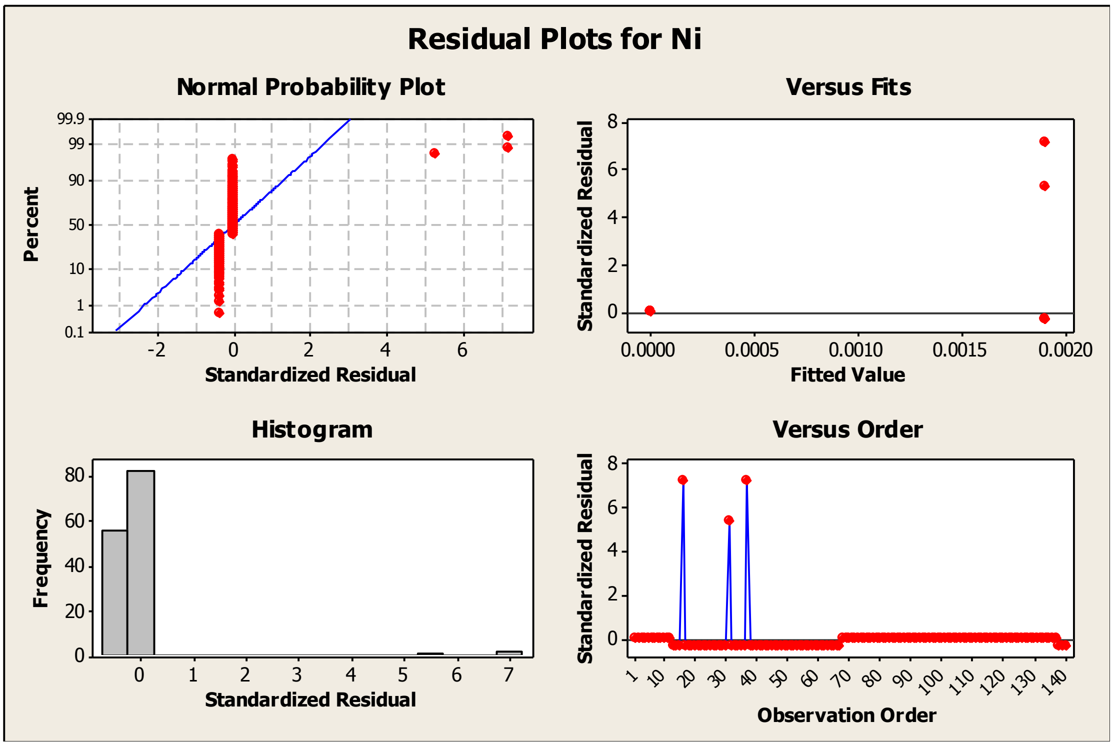
S = 0.00534912   R-Sq = 3.04%   R-Sq(adj) = 0.91%

Unusual Observations for Ni

Obs	Ni	Fit	SE Fit	Residual	St Resid
16	0.040000	0.001897	0.000702	0.038103	7.19 R
31	0.030000	0.001897	0.000702	0.028103	5.30 R
37	0.040000	0.001897	0.000702	0.038103	7.19 R

R denotes an observation with a large standardized residual.

Residual Plots for Ni



Ni = NOT normally distributed – *too few samples*

Appendix 9: One way ANOVA's comparing the A horizons of each site

One-way ANOVA: Na versus Site

```
Source  DF      SS      MS     F      P
Site     6  1.0280  0.1713  7.65  0.000
Error   20  0.4478  0.0224
Total   26  1.4758

S = 0.1496   R-Sq = 69.66%   R-Sq(adj) = 60.56%


                                Individual 95% CIs For Mean Based on
                                Pooled StDev
Level  N    Mean   StDev  ------+---------+---------+---------+---
1      2  0.0600  0.0849  (-------*--------)
2      1  0.1800       *   (-----------*------------)
3      3  0.0967  0.1422     (------*------)
4      3  0.0300  0.0265  (------*------)
5      9  0.4978  0.1919                      (---*---)
6      6  0.3367  0.1347              (----*-----)
7      3  0.5700  0.0819                      (------*------)
                          ------+---------+---------+---------+---
                              0.00      0.25      0.50      0.75

Pooled StDev = 0.1496
```

Key: Site 1 = Prästsjödiket
Site 2 = Unused site
Site 3 = Lass Mass Heden
Site 4 = Tjärdal
Site 5 = Hornmyr
Site 6 = Gammelhemmet
Site 7 = Kåddis

One-way ANOVA: Mg versus Site

```
Source  DF      SS     MS      F      P
Site     6   8.010  1.335  12.60  0.000
Error   20   2.119  0.106
Total   26  10.129

S = 0.3255   R-Sq = 79.08%   R-Sq(adj) = 72.81%


                           Individual 95% CIs For Mean Based on Pooled StDev
Level  N    Mean   StDev      +---------+---------+---------+---------
1      2  0.0000  0.0000         (------*------)
2      1  0.0000       *      (---------*---------)
3      3  0.0933  0.1617            (----*-----)
4      3  0.0000  0.0000          (-----*-----)
5      9  0.1189  0.0551              (---*--)
6      6  0.9733  0.6205                       (---*---)
7      3  1.5733  0.2419                              (----*-----)
                              +---------+---------+---------+---------
                           -0.70      0.00      0.70      1.40

Pooled StDev = 0.3255
```

One-way ANOVA: Al versus Site

```
Source  DF      SS     MS      F      P
Site     6  198.00  33.00  10.83  0.000
Error   20   60.94   3.05
Total   26  258.94

S = 1.746   R-Sq = 76.47%   R-Sq(adj) = 69.41%


                         Individual 95% CIs For Mean Based on
                         Pooled StDev
Level  N   Mean  StDev   ---------+---------+---------+---------+
1      2  0.415  0.346      (------*-------)
2      1  0.400      *   (---------*----------)
3      3  0.623  0.778        (-----*-----)
4      3  0.190  0.036       (-----*-----)
5      9  1.554  0.473             (--*---)
6      6  5.345  3.344                       (---*----)
7      3  8.380  0.979                              (-----*-----)
                         ---------+---------+---------+---------+
                               0.0       3.5       7.0      10.5

Pooled StDev = 1.746
```

One-way ANOVA: Si versus Site

```
Source  DF      SS     MS      F      P
Site     6  310.65  51.77  15.09  0.000
Error   20   68.64   3.43
Total   26  379.29

S = 1.853   R-Sq = 81.90%   R-Sq(adj) = 76.47%


                            Individual 95% CIs For Mean Based on
                            Pooled StDev
Level  N   Mean  StDev  -------+---------+---------+---------+--
1      2  1.330  1.541    (--------*---------)
2      1  1.680      *  (------------*-----------)
3      3  2.163  2.571         (------*-------)
4      3  0.643  0.346    (------*-------)
5      9  7.884  2.519                              (---*----)
6      6  0.297  0.639     (----*----)
7      3  0.013  0.006  (------*------)
                        -------+---------+---------+---------+--
                             0.0       3.0       6.0       9.0

Pooled StDev = 1.853
```

One-way ANOVA: P versus Site

```
Source  DF      SS      MS      F      P
Site     6  1.2490  0.2082  11.85  0.000
Error   20  0.3515  0.0176
Total   26  1.6005

S = 0.1326   R-Sq = 78.04%   R-Sq(adj) = 71.45%


                              Individual 95% CIs For Mean Based on
                              Pooled StDev
Level  N    Mean   StDev  ---------+---------+---------+---------+
1      2  0.0050  0.0071     (-----*------)
2      1  0.0100       *  (--------*---------)
3      3  0.0333  0.0404       (----*----)
4      3  0.0100  0.0100      (----*-----)
5      9  0.0578  0.0335          (--*--)
6      6  0.3400  0.2425                 (--*---)
7      3  0.6700  0.1500                          (----*-----)
                          ---------+---------+---------+---------+
                                0.00      0.30      0.60      0.90

Pooled StDev = 0.1326
```

One-way ANOVA: K versus Site

```
Source  DF      SS      MS     F      P
Site     6  0.7546  0.1258  5.32  0.002
Error   20  0.4731  0.0237
Total   26  1.2277

S = 0.1538   R-Sq = 61.46%   R-Sq(adj) = 49.90%


                              Individual 95% CIs For Mean Based on
                              Pooled StDev
Level  N    Mean   StDev  ---------+---------+---------+---------+
1      2  0.0750  0.1061     (--------*--------)
2      1  0.1000       *  (------------*------------)
3      3  0.2167  0.3086            (-------*------)
4      3  0.0167  0.0208    (-------*------)
5      9  0.4822  0.1682                        (---*----)
6      6  0.1850  0.0857             (----*-----)
7      3  0.2600  0.0608              (------*-------)
                          ---------+---------+---------+---------+
                                0.00      0.25      0.50      0.75

Pooled StDev = 0.1538
```

One-way ANOVA: Ca versus Site

```
Source  DF      SS      MS     F      P
Site     6  0.4911  0.0819  5.19  0.002
Error   20  0.3157  0.0158
Total   26  0.8069

S = 0.1256   R-Sq = 60.87%   R-Sq(adj) = 49.13%


                              Individual 95% CIs For Mean Based on
                              Pooled StDev
Level  N    Mean   StDev  --------+---------+---------+---------+-
1      2  0.1250  0.0354       (--------*---------)
2      1  0.1000       *  (------------*------------)
3      3  0.1400  0.0700         (--------*-------)
4      3  0.0900  0.0361       (-------*------)
5      9  0.3267  0.0962                    (---*----)
6      6  0.4617  0.2082                          (----*----)
7      3  0.3800  0.0755                   (-------*--------)
                          --------+---------+---------+---------+-
                               0.00      0.20      0.40      0.60

Pooled StDev = 0.1256
```

One-way ANOVA: Ti versus Site

Source	DF	SS	MS	F	P
Site	6	0.02435	0.00406	2.80	0.038
Error	20	0.02902	0.00145		
Total	26	0.05336			

S = 0.03809   R-Sq = 45.62%   R-Sq(adj) = 29.31%

```
                                 Individual 95% CIs For Mean Based on
                                 Pooled StDev
Level  N     Mean    StDev  ------+---------+---------+---------+---
1      2  0.01000  0.01414         (----------*----------)
2      1  0.00000        *  (---------------*---------------)
3      3  0.03333  0.05774               (---------*--------)
4      3  0.00000  0.00000         (--------*--------)
5      9  0.08000  0.03279                              (----*----)
6      6  0.06167  0.04834                         (-----*------)
7      3  0.07333  0.03055                        (----------*--------)
                            ------+---------+---------+---------+---
                               -0.050     0.000     0.050     0.100
```

Pooled StDev = 0.03809

One-way ANOVA: Fe versus Site

Source	DF	SS	MS	F	P
Site	6	1.9419	0.3236	3.32	0.020
Error	20	1.9494	0.0975		
Total	26	3.8913			

S = 0.3122   R-Sq = 49.90%   R-Sq(adj) = 34.87%

```
                               Individual 95% CIs For Mean Based on
                               Pooled StDev
Level  N    Mean   StDev   --+---------+---------+---------+-------
1      2  0.2950  0.0636           (----------*-----------)
2      1  0.1900       *    (----------------*---------------)
3      3  0.6767  0.8864                      (---------*--------)
4      3  0.2233  0.0945           (---------*--------)
5      9  0.6422  0.2072                         (----*----)
6      6  0.0800  0.0486          (------*------)
7      3  0.0133  0.0231      (--------*---------)
                           --+---------+---------+---------+-------
                           -0.40      0.00      0.40      0.80
```

Pooled StDev = 0.3122

One-way ANOVA: Cl versus Site

```
Source  DF       SS       MS     F      P
Site     6  0.04147  0.00691  3.34  0.019
Error   20  0.04136  0.00207
Total   26  0.08283

S = 0.04547   R-Sq = 50.07%   R-Sq(adj) = 35.09%


                                Individual 95% CIs For Mean Based on
                                Pooled StDev
Level  N     Mean    StDev  -------+---------+---------+---------+--
1      2  0.04000  0.02828    (-----------*----------)
2      1  0.05000        *  (--------------*---------------)
3      3  0.14000  0.12166                      (---------*--------)
4      3  0.03333  0.03512     (---------*--------)
5      9  0.00889  0.01453     (----*-----)
6      6  0.02000  0.03633      (-----*------)
7      3  0.02000  0.01000   (--------*--------)
                            -------+---------+---------+---------+--
                                 0.000     0.060     0.120     0.180

Pooled StDev = 0.04547
```

One-way ANOVA: Mn versus Site

```
Source  DF         SS         MS     F      P
Site     6  0.0000519  0.0000086  0.52  0.787
Error   20  0.0003333  0.0000167
Total   26  0.0003852

S = 0.004082   R-Sq = 13.46%   R-Sq(adj) = 0.00%


                                  Individual 95% CIs For Mean Based on
                                  Pooled StDev
Level  N      Mean     StDev  -------+---------+---------+---------+--
1      2  0.000000  0.000000       (-----------*-----------)
2      1  0.000000         *  (----------------*----------------)
3      3  0.000000  0.000000         (---------*---------)
4      3  0.000000  0.000000         (---------*---------)
5      9  0.000000  0.000000             (-----*-----)
6      6  0.003333  0.008165                   (------*------)
7      3  0.000000  0.000000         (---------*---------)
                              -------+---------+---------+---------+--
                                  -0.0050    0.0000    0.0050    0.0100

Pooled StDev = 0.004082
```

One-way ANOVA: S versus Site

```
Source  DF         SS         MS  F  P
Site     6  0.0000000  0.0000000  *  *
Error   20  0.0000000  0.0000000
Total   26  0.0000000
S = 0   R-Sq = *%   R-Sq(adj) = *%

Level  N         Mean        StDev
1      2  0.000000000  0.000000000
2      1  0.000000000            *
3      3  0.000000000  0.000000000
4      3  0.000000000  0.000000000
5      9  0.000000000  0.000000000
6      6  0.000000000  0.000000000
7      3  0.000000000  0.000000000

       Individual 95% CIs For Mean Based on Pooled StDev
Level    +---------+---------+---------+---------
1        *
2        *
3        *
4        *
5        *
6        *
7        *
         +---------+---------+---------+---------
       0.000000  0.000010  0.000020  0.000030

Pooled StDev = 0.000000000
```


One-way ANOVA: S versus Site

```
Source  DF         SS         MS  F  P
Site     6  0.0000000  0.0000000  *  *
Error   20  0.0000000  0.0000000
Total   26  0.0000000

S = 0   R-Sq = *%   R-Sq(adj) = *%
Level  N         Mean        StDev
1      2  0.000000000  0.000000000
2      1  0.000000000            *
3      3  0.000000000  0.000000000
4      3  0.000000000  0.000000000
5      9  0.000000000  0.000000000
6      6  0.000000000  0.000000000
7      3  0.000000000  0.000000000

       Individual 95% CIs For Mean Based on Pooled StDev
Level    +---------+---------+---------+---------
1        *
2        *
3        *
4        *
5        *
6        *
7        *
         +---------+---------+---------+---------
       0.000000  0.000010  0.000020  0.000030
```

Appendix 10: One way ANOVA's comparing the E horizons of each site

One-way ANOVA: Na versus Site

```
Source  DF      SS      MS     F      P
Site     6  0.4267  0.0711  3.99  0.004
Error   34  0.6052  0.0178
Total   40  1.0319

S = 0.1334   R-Sq = 41.35%   R-Sq(adj) = 31.00%


                           Individual 95% CIs For Mean Based on
                           Pooled StDev
Level   N    Mean   StDev  -------+---------+---------+---------+--
1      11  0.5991  0.1600                    (----*-----)
2       3  0.6767  0.0404                     (---------*---------)
3       7  0.5271  0.0275               (-----*-----)
4       5  0.3240  0.1747  (-------*--------)
5       6  0.4633  0.1181          (-------*-------)
6       6  0.4983  0.0870            (-------*-------)
7       3  0.3600  0.2364  (----------*---------)
                           -------+---------+---------+---------+--
                                0.32      0.48      0.64      0.80
Pooled StDev = 0.1334
```

Key: Site 1 = Prästsjödiket
Site 2 = Unused site
Site 3 = Lass Mass Heden
Site 4 = Tjärdal
Site 5 = Hornmyr
Site 6 = Gammelhemmet
Site 7 = Kåddis

One-way ANOVA: Mg versus Site

```
Source  DF       SS       MS     F      P
Site     6  0.09549  0.01592  3.77  0.005
Error   34  0.14335  0.00422
Total   40  0.23884

S = 0.06493   R-Sq = 39.98%   R-Sq(adj) = 29.39%


                             Individual 95% CIs For Mean Based on Pooled StDev
Level   N     Mean    StDev     +---------+---------+---------+---------
1      11  0.15636  0.09595                               (----*----)
2       3  0.14667  0.10504                          (---------*----------)
3       7  0.04286  0.03147                (-----*------)
4       5  0.09600  0.06580                      (-------*-------)
5       6  0.09167  0.02317                      (------*------)
6       6  0.08833  0.02563                     (------*-------)
7       3  0.00000  0.00000     (----------*----------)
                                +---------+---------+---------+---------
```

One-way ANOVA: Al versus Site

```
Source  DF     SS     MS     F      P
Site     6  3.102  0.517  3.62  0.007
Error   34  4.853  0.143
Total   40  7.955

S = 0.3778   R-Sq = 39.00%   R-Sq(adj) = 28.23%


                               Individual 95% CIs For Mean Based on
                               Pooled StDev
Level   N    Mean   StDev  --------+---------+---------+---------+-
1      11  1.6955  0.4388                   (----*----)
2       3  1.9167  0.2501                   (---------*---------)
3       7  1.5000  0.3254              (-----*-----)
4       5  0.9440  0.4158  (------*------)
5       6  1.4117  0.3206            (-----*------)
6       6  1.3867  0.2286           (------*-----)
7       3  1.0600  0.5915  (---------*--------)
                           --------+---------+---------+---------+-
                                1.00      1.50      2.00      2.50

Pooled StDev = 0.3778
```

One-way ANOVA: Si versus Site

```
Source  DF      SS    MS     F      P
Site     6   44.36  7.39  1.29  0.288
Error   34  194.86  5.73
Total   40  239.22

S = 2.394   R-Sq = 18.54%   R-Sq(adj) = 4.17%


                              Individual 95% CIs For Mean Based on
                              Pooled StDev
Level   N    Mean  StDev  -----+---------+---------+---------+----
1      11   8.443  2.287              (-----*-----)
2       3   9.300  0.632            (----------*----------)
3       7  10.190  1.479                   (--------*-------)
4       5   7.204  3.379       (---------*---------)
5       6   9.438  2.824                (--------*--------)
6       6   8.638  1.055             (-------*-------)
7       3   6.657  4.330  (-----------*-----------)
                          -----+---------+---------+---------+----
                             5.0       7.5      10.0      12.5

Pooled StDev = 2.394
```

One-way ANOVA: P versus Site

```
Source  DF        SS        MS     F      P
Site     6  0.015431  0.002572  8.00  0.000
Error   34  0.010930  0.000321
Total   40  0.026361

S = 0.01793   R-Sq = 58.54%   R-Sq(adj) = 51.22%


                             Individual 95% CIs For Mean Based on
                             Pooled StDev
Level   N     Mean    StDev  --------+---------+---------+---------+-
1      11  0.02091  0.02119              (---*----)
2       3  0.01000  0.01732      (-------*-------)
3       7  0.06143  0.02478                                (-----*----)
4       5  0.01400  0.01673         (------*-----)
5       6  0.01167  0.00753         (-----*-----)
6       6  0.00500  0.01225      (-----*-----)
7       3  0.00000  0.00000  (-------*-------)
                             --------+---------+---------+---------+-
                                   0.000     0.025     0.050     0.075

Pooled StDev = 0.01793
```

One-way ANOVA: K versus Site

```
Source  DF      SS      MS     F      P
Site     6  0.5188  0.0865  2.23  0.063
Error   34  1.3154  0.0387
Total   40  1.8342

S = 0.1967   R-Sq = 28.28%   R-Sq(adj) = 15.63%


                           Individual 95% CIs For Mean Based on
                           Pooled StDev
Level   N    Mean   StDev  --+---------+---------+---------+-------
1      11  0.6309  0.1583             (----*----)
2       3  0.8933  0.3362                    (---------*---------)     - Lycksele
3       7  0.5957  0.1306           (-----*-----)
4       5  0.3880  0.1983  (-------*-------)
5       6  0.5717  0.1619         (-------*-----)
6       6  0.5517  0.1419         (-----*------)
7       3  0.5333  0.4168     (---------*---------)
                           --+---------+---------+---------+-------
                           0.25      0.50      0.75      1.00

Pooled StDev = 0.1967
```

One-way ANOVA: Ca versus Site

```
Source  DF      SS    MS     F      P
Site     6   46.01  7.67  0.78  0.592
Error   34  334.70  9.84
Total   40  380.71

S = 3.138   R-Sq = 12.09%   R-Sq(adj) = 0.00%


                             Individual 95% CIs For Mean Based on
                             Pooled StDev
Level   N   Mean  StDev  ----+---------+---------+---------+-----
1      11  0.280  0.096         (-------*-------)
2       3  0.287  0.067  (--------------*--------------)
3       7  3.067  7.467                   (---------*---------)
4       5  0.212  0.094     (-----------*----------)
5       6  0.268  0.048       (---------*---------)
6       6  0.253  0.082       (---------*---------)
7       3  0.160  0.000  (--------------*-------------)
                         ----+---------+---------+---------+-----
                          -2.5       0.0       2.5       5.0

Pooled StDev = 3.138
```

One-way ANOVA: Ti versus Site

```
Source  DF       SS       MS     F      P
Site     6  0.03649  0.00608  3.98  0.004
Error   34  0.05202  0.00153
Total   40  0.08851

S = 0.03911   R-Sq = 41.23%   R-Sq(adj) = 30.86%


                                 Individual 95% CIs For Mean Based on Pooled StDev
Level   N     Mean    StDev  ---------+---------+---------+---------+
1      11  0.06545  0.04156                  (----*----)
2       3  0.06000  0.05292             (---------*---------)
3       7  0.11714  0.04821                           (-----*-----)
4       5  0.09400  0.04278                      (-------*-------)
5       6  0.09167  0.03764                      (-----*------)
6       6  0.10000  0.01265                        (-----*-----)
7       3  0.00000  0.00000  (--------*--------)
                             ---------+---------+---------+---------+
                                  0.000     0.050     0.100     0.150

Pooled StDev = 0.03911
```

One-way ANOVA: Fe versus Site

```
Source  DF      SS      MS     F      P
Site     6  0.3930  0.0655  1.09  0.389
Error   34  2.0465  0.0602
Total   40  2.4395

S = 0.2453   R-Sq = 16.11%   R-Sq(adj) = 1.30%


                           Individual 95% CIs For Mean Based on
                           Pooled StDev
Level   N    Mean   StDev  --+---------+---------+---------+-------
1      11  0.5427  0.2689                    (-----*------)
2       3  0.5767  0.3863                (----------*-----------)
3       7  0.4014  0.2691             (------*-------)
4       5  0.3200  0.0768        (--------*--------)
5       6  0.4283  0.2943             (-------*-------)
6       6  0.3700  0.1273           (-------*-------)
7       3  0.2467  0.1626  (-----------*----------)
                           --+---------+---------+---------+-------
                           0.00      0.25      0.50      0.75

Pooled StDev = 0.2453
```

One-way ANOVA: Cl versus Site

```
Source  DF        SS        MS     F      P
Site     6  0.016777  0.002796  8.10  0.000
Error   34  0.011736  0.000345
Total   40  0.028512

S = 0.01858   R-Sq = 58.84%   R-Sq(adj) = 51.58%


                             Individual 95% CIs For Mean Based on Pooled StDev
Level   N     Mean    StDev  ---------+---------+---------+---------+
1      11  0.01455  0.01293            (----*---)
2       3  0.00000  0.00000  (--------*--------)
3       7  0.05714  0.03302                            (-----*-----)
4       5  0.01600  0.01140           (-----*------)
5       6  0.01000  0.01673         (-----*-----)
6       6  0.00333  0.00816      (-----*-----)
7       3  0.05333  0.02517                        (--------*--------)
                             ---------+---------+---------+---------+
                                    0.000     0.025     0.050     0.075

Pooled StDev = 0.01858
```

One-way ANOVA: Mn versus Site

```
Source  DF         SS         MS  F  P
Site     6  0.0000000  0.0000000  *  *
Error   34  0.0000000  0.0000000
Total   40  0.0000000

S = 0   R-Sq = *%   R-Sq(adj) = *%



Level   N         Mean        StDev
1      11  0.000000000  0.000000000
2       3  0.000000000  0.000000000
3       7  0.000000000  0.000000000
4       5  0.000000000  0.000000000
5       6  0.000000000  0.000000000
6       6  0.000000000  0.000000000
7       3  0.000000000  0.000000000

       Individual 95% CIs For Mean Based on Pooled StDev
Level    +---------+---------+---------+---------
1        *
2        *
3        *
4        *
5        *
6        *
7        *
         +---------+---------+---------+---------
       0.000000  0.000010  0.000020  0.000030

Pooled StDev = 0.000000000
```

One-way ANOVA: S versus Site

```
Source  DF        SS        MS     F      P
Site     6  0.002523  0.000420  1.31  0.279
Error   34  0.010897  0.000320
Total   40  0.013420

S = 0.01790   R-Sq = 18.80%   R-Sq(adj) = 4.47%


                             Individual 95% CIs For Mean Based on
                             Pooled StDev
Level   N     Mean    StDev  ----+---------+---------+---------+-----
1      11  0.01818  0.03250                    (------*------)
2       3  0.00000  0.00000  (--------------*--------------)
3       7  0.00000  0.00000       (---------*---------)
4       5  0.00000  0.00000     (-----------*-----------)
5       6  0.00333  0.00816        (----------*----------)
6       6  0.00000  0.00000      (----------*----------)
7       3  0.00000  0.00000  (--------------*--------------)
                             ----+---------+---------+---------+-----
                              -0.015     0.000     0.015     0.030

Pooled StDev = 0.01790
```

One-way ANOVA: Ni versus Site

```
Source  DF         SS         MS  F  P
Site     6  0.0000000  0.0000000  *  *
Error   34  0.0000000  0.0000000
Total   40  0.0000000

S = 0   R-Sq = *%   R-Sq(adj) = *%



Level   N         Mean        StDev
1      11  0.000000000  0.000000000
2       3  0.000000000  0.000000000
3       7  0.000000000  0.000000000
4       5  0.000000000  0.000000000
5       6  0.000000000  0.000000000
6       6  0.000000000  0.000000000
7       3  0.000000000  0.000000000

       Individual 95% CIs For Mean Based on Pooled StDev
Level    +---------+---------+---------+---------
1        *
2        *
3        *
4        *
5        *
6        *
7        *
         +---------+---------+---------+---------
       0.000000  0.000010  0.000020  0.000030

Pooled StDev = 0.000000000
```

Appendix 11: One way ANOVA's comparing the B horizons of each site

One-way ANOVA: Na versus Site

```
Source  DF      SS      MS     F      P
Site     5  0.6154  0.1231  3.90  0.012
Error   21  0.6623  0.0315
Total   26  1.2776

S = 0.1776   R-Sq = 48.16%   R-Sq(adj) = 35.82%


                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Level  N    Mean   StDev  --+---------+---------+---------+-------
2      3  0.5000  0.2498               (--------*--------)
3      8  0.3050  0.2018           (----*----)
4      2  0.2150  0.3041  (----------*---------)
5      4  0.5000  0.1465                 (------*------)
6      6  0.5200  0.1346                   (-----*-----)
7      4  0.7200  0.0408                         (-------*------)
                          --+---------+---------+---------+-------
                          0.00      0.25      0.50      0.75

Pooled StDev = 0.1776
```

Key: Site 1 = Prästsjödiket
Site 3 = Lass Mass Heden
Site 4 = Tjärdal
Site 5 = Hornmyr
Site 6 = Gammelhemmet
Site 7 = Kåddis

One-way ANOVA: Mg versus Site

```
Source  DF       SS       MS     F      P
Site     5  0.01375  0.00275  0.85  0.531
Error   21  0.06812  0.00324
Total   26  0.08187

S = 0.05695   R-Sq = 16.80%   R-Sq(adj) = 0.00%


                            Individual 95% CIs For Mean Based on Pooled StDev
Level  N     Mean    StDev    +---------+---------+---------+---------
2      3  0.10667  0.06028            (-------------*-------------)
3      8  0.11250  0.07573                  (---------*--------)
4      2  0.10000  0.05657       (----------------*----------------)
5      4  0.12750  0.03403                  (-----------*----------)
6      6  0.12500  0.04183                   (----------*---------)
7      4  0.05750  0.04193    (-----------*----------)
                              +---------+---------+---------+---------
                            0.000     0.050     0.100     0.150

Pooled StDev = 0.05695
```

One-way ANOVA: Al versus Site

```
Source  DF      SS      MS     F      P
Site     5  0.5869  0.1174  1.26  0.316
Error   21  1.9505  0.0929
Total   26  2.5374

S = 0.3048   R-Sq = 23.13%   R-Sq(adj) = 4.83%


                           Individual 95% CIs For Mean Based on
                           Pooled StDev
Level  N    Mean   StDev   ---+---------+---------+---------+------
2      3  1.3833  0.5082     (----------*---------)
3      8  1.5437  0.3605              (-----*------)
4      2  1.3900  0.0707   (------------*------------)
5      4  1.6250  0.2517             (--------*--------)
6      6  1.7433  0.2414                  (-------*------)
7      4  1.8300  0.1122                   (--------*--------)
                           ---+---------+---------+---------+------
                            1.05      1.40      1.75      2.10

Pooled StDev = 0.3048
```

One-way ANOVA: Si versus Site

```
Source  DF     SS    MS     F      P
Site     5  29.75  5.95  2.76  0.046
Error   21  45.30  2.16
Total   26  75.05

S = 1.469   R-Sq = 39.64%   R-Sq(adj) = 25.27%


                         Individual 95% CIs For Mean Based on
                         Pooled StDev
Level  N   Mean  StDev  ---------+---------+---------+---------+
2      3  6.687  2.832  (----------*----------)
3      8  6.563  1.292     (------*------)
4      2  7.385  1.450    (------------*-------------)
5      4  7.143  0.550      (---------*--------)
6      6  7.847  1.673            (-------*-------)
7      4  9.707  0.440                      (---------*--------)
                        ---------+---------+---------+---------+
                               6.4       8.0       9.6      11.2

Pooled StDev = 1.469
```

One-way ANOVA: P versus Site

```
Source  DF        SS        MS     F      P
Site     5  0.013584  0.002717  6.04  0.001
Error   21  0.009446  0.000450
Total   26  0.023030

S = 0.02121   R-Sq = 58.98%   R-Sq(adj) = 49.22%


                            Individual 95% CIs For Mean Based on
                            Pooled StDev
Level  N     Mean    StDev  --------+---------+---------+---------+-
2      3  0.02000  0.02646        (---------*---------)
3      8  0.06375  0.02504                             (-----*------)
4      2  0.02000  0.02828      (-----------*-----------)
5      4  0.01500  0.02380       (--------*--------)
6      6  0.03833  0.01472                  (------*-------)
7      4  0.00250  0.00500  (--------*--------)
                            --------+---------+---------+---------+-
                                  0.000     0.025     0.050     0.075

Pooled StDev = 0.02121
```

One-way ANOVA: K versus Site

```
Source  DF      SS      MS     F      P
Site     5  0.4305  0.0861  4.45  0.006
Error   21  0.4064  0.0194
Total   26  0.8369

S = 0.1391   R-Sq = 51.44%   R-Sq(adj) = 39.88%


                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Level  N    Mean   StDev  --------+---------+---------+---------+-
2      3  0.5233  0.2859        (-------*--------)
3      8  0.3800  0.1259    (----*----)
4      2  0.4450  0.1344  (---------*---------)
5      4  0.4275  0.0512    (------*-------)
6      6  0.5133  0.1341          (-----*-----)
7      4  0.7675  0.0732                     (------*-------)
                          --------+---------+---------+---------+-
                                0.40      0.60      0.80      1.00

Pooled StDev = 0.1391
```

One-way ANOVA: Ca versus Site

```
Source  DF       SS       MS     F      P
Site     5  0.01659  0.00332  0.98  0.451
Error   21  0.07081  0.00337
Total   26  0.08740

S = 0.05807   R-Sq = 18.98%   R-Sq(adj) = 0.00%


                            Individual 95% CIs For Mean Based on
                            Pooled StDev
Level  N     Mean    StDev  ----+---------+---------+---------+-----
2      3  0.29000  0.09644             (----------*-----------)
3      8  0.23500  0.03854        (------*------)
4      2  0.24000  0.04243  (-------------*-------------)
5      4  0.29750  0.06185                (---------*---------)
6      6  0.28333  0.07202               (-------*-------)
7      4  0.27000  0.02944           (---------*---------)
                            ----+---------+---------+---------+-----
                              0.180     0.240     0.300     0.360

Pooled StDev = 0.05807
```

One-way ANOVA: Ti versus Site

```
Source  DF        SS        MS     F      P
Site     5  0.019691  0.003938  6.44  0.001
Error   21  0.012850  0.000612
Total   26  0.032541

S = 0.02474   R-Sq = 60.51%   R-Sq(adj) = 51.11%


                            Individual 95% CIs For Mean Based on
                            Pooled StDev
Level  N     Mean    StDev  ---+---------+---------+---------+------
2      3  0.06667  0.01155              (-------*------)
3      8  0.09500  0.02070                        (----*---)
4      2  0.10000  0.00000                     (---------*--------)
5      4  0.06000  0.04082              (-----*-----)
6      6  0.07833  0.01941                   (-----*----)
7      4  0.01500  0.03000  (------*-----)
                            ---+---------+---------+---------+------
                             0.000     0.040     0.080     0.120

Pooled StDev = 0.02474
```

One-way ANOVA: Fe versus Site

```
Source  DF      SS      MS     F      P
Site     5  1.3452  0.2690  4.10  0.009
Error   21  1.3789  0.0657
Total   26  2.7241

S = 0.2562   R-Sq = 49.38%   R-Sq(adj) = 37.33%


                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Level  N    Mean   StDev  --------+---------+---------+---------+-
2      3  0.5433  0.2230        (----------*----------)
3      8  0.9888  0.3838                           (-----*-----)
4      2  0.5500  0.4243      (------------*------------)
5      4  0.6925  0.0369              (---------*---------)
6      6  0.7517  0.1007                  (------*------)
7      4  0.3300  0.0668  (---------*---------)
                          --------+---------+---------+---------+-
                                0.30      0.60      0.90      1.20

Pooled StDev = 0.2562
```

One-way ANOVA: Cl versus Site

```
Source  DF        SS        MS     F      P
Site     5  0.017904  0.003581  4.96  0.004
Error   21  0.015163  0.000722
Total   26  0.033067

S = 0.02687   R-Sq = 54.15%   R-Sq(adj) = 43.23%


                            Individual 95% CIs For Mean Based on Pooled StDev
Level  N     Mean    StDev    -+---------+---------+---------+--------
2      3  0.01333  0.01155          (---------*---------)
3      8  0.06375  0.04373                            (----*-----)
4      2  0.00000  0.00000    (-----------*-----------)
5      4  0.00500  0.01000        (--------*--------)
6      6  0.00667  0.01033          (------*-----)
7      4  0.01250  0.01500           (--------*--------)
                              -+---------+---------+---------+--------
                            -0.035     0.000     0.035     0.070

Pooled StDev = 0.02687
```

One-way ANOVA: Mn versus Site

```
Source   DF          SS          MS  F  P
Site      5  0.0000000  0.0000000  *  *
Error    21  0.0000000  0.0000000
Total    26  0.0000000

S = 0   R-Sq = *%   R-Sq(adj) = *%



Level  N         Mean        StDev
2      3  0.000000000  0.000000000
3      8  0.000000000  0.000000000
4      2  0.000000000  0.000000000
5      4  0.000000000  0.000000000
6      6  0.000000000  0.000000000
7      4  0.000000000  0.000000000

       Individual 95% CIs For Mean Based on Pooled StDev
Level    +---------+---------+---------+---------
2        *
3        *
4        *
5        *
6        *
7        *
         +---------+---------+---------+---------
       0.000000  0.000010  0.000020  0.000030

Pooled StDev = 0.000000000
```

One-way ANOVA: S versus Site

```
Source   DF        SS        MS     F      P
Site      5  0.06000  0.01200  3.89  0.012
Error    21  0.06480  0.00309
Total    26  0.12480

S = 0.05555   R-Sq = 48.08%   R-Sq(adj) = 35.71%


                             Individual 95% CIs For Mean Based on
                             Pooled StDev
Level  N     Mean    StDev   -------+---------+---------+---------+--
2      3  0.00000  0.00000   (------*------)
3      8  0.00000  0.00000      (---*---)
4      2  0.18000  0.25456                    (-------*-------)
5      4  0.00000  0.00000    (-----*-----)
6      6  0.00000  0.00000     (----*----)
7      4  0.00000  0.00000    (-----*-----)
                             -------+---------+---------+---------+--
                                 0.00      0.10      0.20      0.30

Pooled StDev = 0.05555
```

One-way ANOVA: Ni versus Site

```
Source  DF         SS         MS  F  P
Site     5  0.0000000  0.0000000  *  *
Error   21  0.0000000  0.0000000
Total   26  0.0000000

S = 0   R-Sq = *%   R-Sq(adj) = *%



Level  N        Mean       StDev
2      3  0.000000000  0.000000000
3      8  0.000000000  0.000000000
4      2  0.000000000  0.000000000
5      4  0.000000000  0.000000000
6      6  0.000000000  0.000000000
7      4  0.000000000  0.000000000

       Individual 95% CIs For Mean Based on Pooled StDev
Level    +---------+---------+---------+---------
2        *
3        *
4        *
5        *
6        *
7        *
         +---------+---------+---------+---------
       0.000000  0.000010  0.000020  0.000030

Pooled StDev = 0.000000000
```

Appendix 12: One way ANOVA's comparing the O horizons of each site

```
Source  DF      SS      MS     F      P
Site     6  0.1544  0.0257  0.88  0.523
Error   27  0.7902  0.0293
Total   33  0.9446

S = 0.1711   R-Sq = 16.34%   R-Sq(adj) = 0.00%


                           Individual 95% CIs For Mean Based on
                           Pooled StDev
Level   N    Mean   StDev  --------+---------+---------+---------+-
1      11  0.0827  0.0986                   (----*----)
3       7  0.2157  0.2523                        (------*-----)
4       1  0.0000       *  (-----------------*-----------------)
5       4  0.2225  0.1590                      (--------*--------)
6       3  0.2300  0.0872                     (----------*---------)
7       6  0.1833  0.2057                      (------*------)
                           --------+---------+---------+---------+-
                               -0.20      0.00      0.20      0.40
Pooled StDev = 0.1711
```

Key: Site 1 = Unused site
Site 3 = Lass Mass Heden
Site 4 = Tjärdal
Site 5 = Hornmyr
Site 6 = Gammelhemmet
Site 7 = Kåddis

One-way ANOVA: Mg versus Site

```
Source  DF        SS        MS     F      P
Site     6  0.002020  0.000337  0.44  0.845
Error   27  0.020630  0.000764
Total   33  0.022650

S = 0.02764   R-Sq = 8.92%   R-Sq(adj) = 0.00%


                             Individual 95% CIs For Mean Based on
                             Pooled StDev
Level   N     Mean    StDev  ------+---------+---------+---------+---
1      11  0.00818  0.02136              (----*----)
3       7  0.02000  0.03606                 (-----*-----)
4       1  0.00000        *  (---------------*---------------)
5       4  0.02000  0.02828               (-------*-------)
6       3  0.02667  0.02309               (---------*--------)
7       6  0.01000  0.02449             (------*-----)
                             ------+---------+---------+---------+---
                                -0.035     0.000     0.035     0.070
Pooled StDev = 0.02764
```

One-way ANOVA: Al versus Site

```
Source  DF     SS     MS     F      P
Site     6  1.025  0.171  0.73  0.629
Error   27  6.308  0.234
Total   33  7.332

S = 0.4833   R-Sq = 13.97%   R-Sq(adj) = 0.00%


                           Individual 95% CIs For Mean Based on
                           Pooled StDev
Level   N    Mean   StDev  ----+---------+---------+---------+-----
1      11  0.3645  0.2550                 (----*----)
2       2  0.3300  0.2404          (-----------*----------)
3       7  0.5514  0.6390                   (-----*-----)
4       1  0.1600       *  (----------------*---------------)
5       4  0.7025  0.4676                   (--------*-------)
6       3  0.5700  0.2563                (---------*--------)
7       6  0.7817  0.6874                      (------*------)
                           ----+---------+---------+---------+-----
                            -0.60      0.00      0.60      1.20

Pooled StDev = 0.4833
```

One-way ANOVA: Si versus Site

```
Source  DF      SS    MS     F      P
Site     6   39.60  6.60  1.13  0.371
Error   27  157.53  5.83
Total   33  197.12

S = 2.415   R-Sq = 20.09%   R-Sq(adj) = 2.33%


                         Individual 95% CIs For Mean Based on
                         Pooled StDev
Level   N   Mean  StDev  ----+---------+---------+---------+-----
1      11  1.124  1.350               (----*----)
2       2  2.345  2.934            (-----------*----------)
3       7  2.487  2.933                  (-----*------)
4       1  0.680      *  (---------------*----------------)
5       4  4.523  3.156                       (-------*-------)
6       3  2.867  1.323                (---------*--------)
7       6  2.662  3.023                  (------*------)
                         ----+---------+---------+---------+-----
                          -3.0       0.0       3.0       6.0

Pooled StDev = 2.415
```

One-way ANOVA: P versus Site

```
Source  DF       SS       MS     F      P
Site     6  0.00435  0.00072  0.33  0.916
Error   27  0.05960  0.00221
Total   33  0.06394

S = 0.04698   R-Sq = 6.80%   R-Sq(adj) = 0.00%


                                 Individual 95% CIs For Mean Based on
                                 Pooled StDev
Level   N     Mean    StDev  -----+---------+---------+---------+----
1      11  0.02364  0.05921               (-----*-----)
2       2  0.00500  0.00707    (-------------*-------------)
3       7  0.04286  0.05992                 (-------*------)
4       1  0.02000        *  (------------------*------------------)
5       4  0.02000  0.01826           (---------*---------)
6       3  0.01667  0.02082         (----------*----------)
7       6  0.01167  0.01472           (-------*-------)
                             -----+---------+---------+---------+----
                               -0.050     0.000     0.050     0.100

Pooled StDev = 0.04698
```

One-way ANOVA: K versus Site

```
Source  DF      SS      MS     F      P
Site     6  0.1573  0.0262  0.80  0.579
Error   27  0.8861  0.0328
Total   33  1.0434

S = 0.1812   R-Sq = 15.07%   R-Sq(adj) = 0.00%


                               Individual 95% CIs For Mean Based on
                               Pooled StDev
Level   N    Mean   StDev  ----+---------+---------+---------+-----
1      11  0.0709  0.0951              (----*---)
2       2  0.0500  0.0707       (----------*----------)
3       7  0.1586  0.2201                 (----*-----)
4       1  0.0100       *  (-------------*--------------)
5       4  0.2625  0.2114                   (-------*------)
6       3  0.1400  0.1179             (--------*-------)
7       6  0.1817  0.2600                 (-----*-----)
                           ----+---------+---------+---------+-----
                            -0.25      0.00      0.25      0.50

Pooled StDev = 0.1812
```

One-way ANOVA: Ca versus Site

```
Source  DF      SS      MS     F      P
Site     6  0.0410  0.0068  0.24  0.960
Error   27  0.7714  0.0286
Total   33  0.8124

S = 0.1690   R-Sq = 5.05%   R-Sq(adj) = 0.00%


                           Individual 95% CIs For Mean Based on
                           Pooled StDev
Level   N    Mean   StDev  -----+---------+---------+---------+----
1      11  0.2073  0.2663                      (----*-----)
2       2  0.1850  0.0636              (------------*------------)
3       7  0.1786  0.0760                   (------*-----)
4       1  0.0500       *  (-----------------*----------------)
5       4  0.1625  0.0369                (---------*--------)
6       3  0.1767  0.0513                (----------*---------)
7       6  0.1283  0.0527                (------*------)
                           -----+---------+---------+---------+----
                             -0.20      0.00      0.20      0.40

Pooled StDev = 0.1690
```

One-way ANOVA: Ti versus Site

```
Source  DF        SS        MS     F      P
Site     6  0.005192  0.000865  0.88  0.524
Error   27  0.026611  0.000986
Total   33  0.031803

S = 0.03139   R-Sq = 16.33%   R-Sq(adj) = 0.00%


                             Individual 95% CIs For Mean Based on
                             Pooled StDev
Level   N     Mean    StDev  --------+---------+---------+---------+-
1      11  0.00545  0.01293                (-----*----)
2       2  0.01000  0.01414          (-------------*------------)
3       7  0.02571  0.04962                    (------*------)
4       1  0.00000        *  (-----------------*------------------)
5       4  0.03500  0.04726                     (---------*--------)
6       3  0.02333  0.04041                (-----------*---------)
7       6  0.00000  0.00000            (-------*-------)
                             --------+---------+---------+---------+-
                                 -0.035     0.000     0.035     0.070

Pooled StDev = 0.03139
```

One-way ANOVA: Fe versus Site

```
Source  DF      SS      MS     F      P
Site     6  0.0470  0.0078  0.58  0.742
Error   27  0.3642  0.0135
Total   33  0.4112

S = 0.1161   R-Sq = 11.44%   R-Sq(adj) = 0.00%


                           Individual 95% CIs For Mean Based on
                           Pooled StDev
Level   N    Mean   StDev  ---+---------+---------+---------+------
1      11  0.2127  0.0986              (----*----)
2       2  0.2500  0.0849          (-----------*----------)
3       7  0.2886  0.1208                  (-----*-----)
4       1  0.1900       *  (---------------*---------------)
5       4  0.2150  0.0443           (-------*-------)
6       3  0.3167  0.1943                 (---------*--------)
7       6  0.2517  0.1348               (------*-----)
                           ---+---------+---------+---------+------
                            0.00      0.15      0.30      0.45

Pooled StDev = 0.1161
```

One-way ANOVA: Cl versus Site

```
Source  DF        SS        MS     F      P
Site     6  0.026221  0.004370  5.57  0.001
Error   27  0.021179  0.000784
Total   33  0.047400

S = 0.02801   R-Sq = 55.32%   R-Sq(adj) = 45.39%


                             Individual 95% CIs For Mean Based on
                             Pooled StDev
Level   N     Mean    StDev  -----+---------+---------+---------+----
1      11  0.03273  0.02936           (---*----)
2       2  0.02500  0.03536   (---------*---------)
3       7  0.09143  0.01864                       (-----*----)
4       1  0.07000        *          (--------------*--------------)
5       4  0.00750  0.01500  (------*-------)
6       3  0.04667  0.04509          (---------*-------)
7       6  0.06833  0.02994                  (-----*-----)
                             -----+---------+---------+---------+----
                               0.000     0.040     0.080     0.120

Pooled StDev = 0.02801
```

One-way ANOVA: Mn versus Site

```
Source   DF         SS         MS  F  P
Site      6  0.0000000  0.0000000  *  *
Error    27  0.0000000  0.0000000
Total    33  0.0000000

S = 0   R-Sq = *%   R-Sq(adj) = *%



Level   N        Mean       StDev
1      11  0.000000000  0.000000000
2       2  0.000000000  0.000000000
3       7  0.000000000  0.000000000
4       1  0.000000000            *
5       4  0.000000000  0.000000000
6       3  0.000000000  0.000000000
7       6  0.000000000  0.000000000

       Individual 95% CIs For Mean Based on Pooled StDev
Level    +---------+---------+---------+---------
1        *
2        *
3        *
4        *
5        *
6        *
7        *
         +---------+---------+---------+---------
       0.000000  0.000010  0.000020  0.000030

Pooled StDev = 0.000000000
```

One-way ANOVA: S versus Site

```
Source   DF        SS        MS     F      P
Site      6  0.035374  0.005896  5.93  0.000
Error    27  0.026850  0.000994
Total    33  0.062224

S = 0.03153   R-Sq = 56.85%   R-Sq(adj) = 47.26%


                             Individual 95% CIs For Mean Based on
                             Pooled StDev
Level   N     Mean    StDev  ------+---------+---------+---------+---
1      11  0.07000  0.05060                               (----*---)
2       2  0.02500  0.03536             (-----------*-----------)
3       7  0.00000  0.00000            (-----*-----)
4       1  0.00000        *  (---------------*---------------)
5       4  0.00000  0.00000          (-------*-------)
6       3  0.00000  0.00000         (---------*---------)
7       6  0.00000  0.00000           (------*------)
                             ------+---------+---------+---------+---
                                -0.040     0.000     0.040     0.080

Pooled StDev = 0.03153
```

One-way ANOVA: Ni versus Site

```
Source  DF         SS         MS     F      P
Site     6  0.0003013  0.0000502  0.66  0.682
Error   27  0.0020545  0.0000761
Total   33  0.0023559

S = 0.008723   R-Sq = 12.79%   R-Sq(adj) = 0.00%


                               Individual 95% CIs For Mean Based on
                               Pooled StDev
Level   N      Mean     StDev  --------+---------+---------+---------+-
1      11  0.006364  0.014334                    (----*-----)
2       2  0.000000  0.000000       (------------*------------)
3       7  0.000000  0.000000             (------*------)
4       1  0.000000         *  (-----------------*-----------------)
5       4  0.000000  0.000000           (--------*--------)
6       3  0.000000  0.000000          (---------*---------)
7       6  0.000000  0.000000             (------*------)
                               --------+---------+---------+---------+-
                                    -0.010     0.000     0.010     0.020

Pooled StDev = 0.008723
```

Appendix 13: One way ANOVA's comparing the average values for the Sámi, European and Control samples to one-another

One-way ANOVA: Na versus Set

```
Source    DF      SS      MS     F      P
Set        3  0.7691  0.2564  4.61  0.004
Error    136  7.5562  0.0556
Total    139  8.3253

S = 0.2357   R-Sq = 9.24%   R-Sq(adj) = 7.24%


                               Individual 95% CIs For Mean Based on
                               Pooled StDev
Level    N    Mean   StDev  --------+---------+---------+---------+-
2       58  0.2767  0.2567  (-----*-----)
3       42  0.4460  0.2087                (-------*------)
4       28  0.3518  0.1956      (--------*--------)
                            --------+---------+---------+---------+-
                                  0.30      0.40      0.50      0.60
Pooled StDev = 0.2357
```

Key: Group 2 = Sámi
Group 3 = European
Group 4 = Control

One-way ANOVA: Mg versus Set

```
Source    DF       SS      MS     F      P
Set        3   1.8591  0.6197  7.08  0.000
Error    136  11.8974  0.0875
Total    139  13.7564

S = 0.2958   R-Sq = 13.51%   R-Sq(adj) = 11.61%

                               Individual 95% CIs For Mean Based on
                               Pooled StDev
Level    N    Mean   StDev  ------+---------+---------+---------+---
2       58  0.0528  0.0792      (-----*------)
3       42  0.3160  0.5248                          (------*-------)
4       28  0.0807  0.0674      (--------*--------)
                            ------+---------+---------+---------+---
                                0.00      0.12      0.24      0.36
Pooled StDev = 0.2958


Grouping Information Using Tukey Method
```

One-way ANOVA: Al versus Set

```
Source   DF      SS     MS     F      P
Set       3   62.72  20.91  9.40  0.000
Error   136  302.43   2.22
Total   139  365.15

S = 1.491   R-Sq = 17.18%   R-Sq(adj) = 15.35%


                         Individual 95% CIs For Mean Based on
                         Pooled StDev
Level   N   Mean  StDev  -----+---------+---------+---------+----
2      58  0.913  0.715     (----*-----)
3      42  2.461  2.517                         (-----*------)
4      28  1.161  0.505      (-------*-------)
                         -----+---------+---------+---------+----
                            0.70      1.40      2.10      2.80

Pooled StDev = 1.491
```

One-way ANOVA: Si versus Set

```
Source   DF      SS    MS     F      P
Set       3    84.3  28.1  1.90  0.132
Error   136  2005.6  14.7
Total   139  2089.9

S = 3.840   R-Sq = 4.03%   R-Sq(adj) = 1.92%


                         Individual 95% CIs For Mean Based on Pooled StDev
Level   N   Mean  StDev    +---------+---------+---------+---------
2      58  4.551  4.005    (-------*-------)
3      42  5.695  4.118            (--------*---------)
4      28  6.553  3.009                 (-----------*-----------)
                           +---------+---------+---------+---------
                         3.6       4.8       6.0       7.2

Pooled StDev = 3.840
```

One-way ANOVA: P versus Set

```
Source   DF      SS      MS     F      P
Set       3  0.2545  0.0848  5.87  0.001
Error   136  1.9662  0.0145
Total   139  2.2207

S = 0.1202   R-Sq = 11.46%   R-Sq(adj) = 9.51%


                           Individual 95% CIs For Mean Based on Pooled StDev
Level   N    Mean   StDev     +---------+---------+---------+---------
2      58  0.0297  0.0405               (----*----)
3      42  0.1171  0.2127                            (------*-----)
4      28  0.0214  0.0240           (-------*------)
                              +---------+---------+---------+---------
                           -0.060     0.000     0.060     0.120

Pooled StDev = 0.1202
```

One-way ANOVA: K versus Set

```
Source   DF       SS      MS     F      P
Set       3   0.4705  0.1568  2.15  0.097
Error   136   9.9222  0.0730
Total   139  10.3928

S = 0.2701   R-Sq = 4.53%   R-Sq(adj) = 2.42%

                               Individual 95% CIs For Mean Based on
                               Pooled StDev
Level   N    Mean   StDev  -------+---------+---------+---------+--
2      58  0.3016  0.2797  (------*------)
3      42  0.4093  0.2386            (-------*-------)
4      28  0.3996  0.2291         (---------*---------)
                           -------+---------+---------+---------+--
                               0.30      0.40      0.50      0.60

Pooled StDev = 0.2701
```

One-way ANOVA: Ca versus Set

```
Source   DF      SS    MS     F      P
Set       3    2.65  0.88  0.31  0.818
Error   136  387.40  2.85
Total   139  390.06

S = 1.688   R-Sq = 0.68%   R-Sq(adj) = 0.00%

                             Individual 95% CIs For Mean Based on
                             Pooled StDev
Level   N   Mean  StDev  ----+---------+---------+---------+-----
2      58  0.541  2.604                  (--------*--------)
3      42  0.295  0.136            (---------*---------)
4      28  0.225  0.075        (------------*------------)
                         ----+---------+---------+---------+-----
                         -0.50      0.00      0.50      1.00

Pooled StDev = 1.688
```

One-way ANOVA: Ti versus Set

```
Source   DF       SS       MS     F      P
Set       3  0.01858  0.00619  2.79  0.043
Error   136  0.30132  0.00222
Total   139  0.31990

S = 0.04707   R-Sq = 5.81%   R-Sq(adj) = 3.73%

                                 Individual 95% CIs For Mean Based on
                                 Pooled StDev
Level   N     Mean    StDev  ---+---------+---------+---------+------
2      58  0.04224  0.04949          (-----*-----)
3      42  0.05905  0.04477                 (-------*------)
4      28  0.07071  0.04898                      (--------*--------)
                             ---+---------+---------+---------+------
                              0.020     0.040     0.060     0.080

Pooled StDev = 0.04707
```

One-way ANOVA: Fe versus Set

Source	DF	SS	MS	F	P
Set	3	0.2342	0.0781	0.80	**0.498**
Error	136	13.3276	0.0980		
Total	139	13.5619			

S = 0.3130   R-Sq = 1.73%   R-Sq(adj) = 0.00%

```
                           Individual 95% CIs For Mean Based on
                           Pooled StDev
Level   N    Mean   StDev  ----+---------+---------+---------+-----
2      58  0.3902  0.3123       (-------*--------)
3      42  0.3900  0.2637     (---------*---------)
4      28  0.4921  0.3852            (-----------*-----------)
                           ----+---------+---------+---------+-----
                             0.30      0.40      0.50      0.60
```

Pooled StDev = 0.3130

One-way ANOVA: Cl versus Set

Source	DF	SS	MS	F	P
Set	3	0.02264	0.00755	5.04	0.002
Error	136	0.20358	0.00150		
Total	139	0.22621			

S = 0.03869   R-Sq = 10.01%   R-Sq(adj) = 8.02%

```
                             Individual 95% CIs For Mean Based on
                             Pooled StDev
Level   N     Mean    StDev  --+---------+---------+---------+-------
2      58  0.04810  0.04685                          (-----*-----)
3      42  0.02024  0.02858         (-------*------)
4      28  0.02964  0.03825             (---------*--------)
                             --+---------+---------+---------+-------
                             0.000     0.016     0.032     0.048
```

Pooled StDev = 0.03869

Appendix 14: Two-Sample T-Test's comparing the overall element concentration at each Sámi site to one another

Two-Sample T-Test and CI: C, site 1, Ca, site 4

```
Two-sample T for C, site 1 vs Ca, site 4

              N    Mean   StDev  SE Mean
C, site 1    27   0.229   0.183    0.035
Ca, site 4    7  0.1414  0.0805    0.030


Difference = mu (C, site 1) - mu (Ca, site 4)
Estimate for difference:  0.0871
95% CI for difference:  (-0.0091, 0.1833)
T-Test of difference = 0 (vs not =): T-Value = 1.87  P-Value = 0.074  DF = 23
```

Two-Sample T-Test and CI: C, site 1, Ca, site 3

```
Two-sample T for C, site 1 vs Ca, site 3

              N    Mean   StDev  SE Mean
C, site 1    27   0.229   0.183    0.035
Ca, site 3   24  0.1821  0.0727    0.015


Difference = mu (C, site 1) - mu (Ca, site 3)
Estimate for difference:  0.0464
95% CI for difference:  (-0.0311, 0.1240)
T-Test of difference = 0 (vs not =): T-Value = 1.22  P-Value = 0.232  DF = 34
```

Two-Sample T-Test and CI: Ca, site 4, Ca, site 3

```
Two-sample T for Ca, site 4 vs Ca, site 3

              N    Mean   StDev  SE Mean
Ca, site 4    7  0.1414  0.0805    0.030
Ca, site 3   24  0.1821  0.0727    0.015


Difference = mu (Ca, site 4) - mu (Ca, site 3)
Estimate for difference:  -0.0407
95% CI for difference:  (-0.1172, 0.0359)
T-Test of difference = 0 (vs not =): T-Value = -1.20  P-Value = 0.260  DF = 9
```

Results for: Worksheet 5

Two-Sample T-Test and CI: Na, Na_1

```
* ERROR * Not enough data in column.
```

<u>Key:</u>

S = A horizon

S_1 = Charred horizon

S_2 = O horizon

Two-Sample T-Test and CI: Na, Na_1

```
Two-sample T for Na vs Na_1

      N   Mean  StDev  SE Mean
Na    8  0.150  0.201    0.071
Na_1  6  0.068  0.105    0.043


Difference = mu (Na) - mu (Na_1)
Estimate for difference:  0.0817
95% CI for difference:  (-0.1034, 0.2667)
T-Test of difference = 0 (vs not =): T-Value = 0.98  P-Value = 0.349  DF = 10
```

Two-Sample T-Test and CI: Na, Na_2

```
Two-sample T for Na vs Na_2

       N   Mean  StDev  SE Mean
Na     8  0.150  0.201    0.071
Na_2  19  0.127  0.178    0.041


Difference = mu (Na) - mu (Na_2)
Estimate for difference:  0.0226
95% CI for difference:  (-0.1581, 0.2033)
T-Test of difference = 0 (vs not =): T-Value = 0.28  P-Value = 0.788  DF = 11
```

Two-Sample T-Test and CI: Na_1, Na_2

```
Two-sample T for Na_1 vs Na_2

       N   Mean  StDev  SE Mean
Na_1   6  0.068  0.105    0.043
Na_2  19  0.127  0.178    0.041


Difference = mu (Na_1) - mu (Na_2)
Estimate for difference:  -0.0590
95% CI for difference:  (-0.1860, 0.0679)
T-Test of difference = 0 (vs not =): T-Value = -1.00  P-Value = 0.335  DF = 14
```

Two-Sample T-Test and CI: Al, Al_1

```
Two-sample T for Al vs Al_1

      N   Mean  StDev  SE Mean
Al    8  0.483  0.455     0.16
Al_1  6  0.477  0.548     0.22


Difference = mu (Al) - mu (Al_1)
Estimate for difference:  0.006
95% CI for difference:  (-0.618, 0.629)
T-Test of difference = 0 (vs not =): T-Value = 0.02  P-Value = 0.984  DF = 9
```

Two-Sample T-Test and CI: Al, Al_2

```
Two-sample T for Al vs Al_2

       N   Mean  StDev  SE Mean
Al     8  0.483  0.455     0.16
Al_2  19  0.423  0.430    0.099


Difference = mu (Al) - mu (Al_2)
Estimate for difference:  0.060
95% CI for difference:  (-0.351, 0.471)
T-Test of difference = 0 (vs not =): T-Value = 0.32  P-Value = 0.756  DF = 12
```

Two-Sample T-Test and CI: Al_1, Al_2

```
Two-sample T for Al_1 vs Al_2

       N   Mean  StDev  SE Mean
Al_1   6  0.477  0.548     0.22
Al_2  19  0.423  0.430    0.099


Difference = mu (Al_1) - mu (Al_2)
Estimate for difference:  0.054
95% CI for difference:  (-0.524, 0.632)
T-Test of difference = 0 (vs not =): T-Value = 0.22  P-Value = 0.831  DF = 7
```

Two-Sample T-Test and CI: P, P_1

```
Two-sample T for P vs P_1

     N    Mean   StDev  SE Mean
P    8  0.0088  0.0113   0.0040
P_1  6  0.0217  0.0293    0.012


Difference = mu (P) - mu (P_1)
Estimate for difference:  -0.0129
95% CI for difference:  (-0.0437, 0.0179)
T-Test of difference = 0 (vs not =): T-Value = -1.03  P-Value = 0.345  DF = 6
```

Two-Sample T-Test and CI: P, P_2

```
Two-sample T for P vs P_2

      N    Mean   StDev  SE Mean
P     8  0.0088  0.0113   0.0040
P_2  19  0.0305  0.0569    0.013


Difference = mu (P) - mu (P_2)
Estimate for difference:  -0.0218
95% CI for difference:  (-0.0502, 0.0066)
T-Test of difference = 0 (vs not =): T-Value = -1.60  P-Value = 0.126  DF = 21
```

Two-Sample T-Test and CI: P_1, P_2

```
Two-sample T for P_1 vs P_2

      N    Mean   StDev  SE Mean
P_1   6  0.0217  0.0293    0.012
P_2  19  0.0305  0.0569    0.013


Difference = mu (P_1) - mu (P_2)
Estimate for difference:  -0.0089
95% CI for difference:  (-0.0462, 0.0285)
T-Test of difference = 0 (vs not =): T-Value = -0.50  P-Value = 0.623  DF = 17
```

Two-Sample T-Test and CI: Cl, Cl_1

```
Two-sample T for Cl vs Cl_1

      N    Mean   StDev  SE Mean
Cl    8  0.0575  0.0396    0.014
Cl_1  6  0.0950  0.0929    0.038


Difference = mu (Cl) - mu (Cl_1)
Estimate for difference:  -0.0375
95% CI for difference:  (-0.1364, 0.0614)
T-Test of difference = 0 (vs not =): T-Value = -0.93  P-Value = 0.389  DF = 6
```

Two-Sample T-Test and CI: Cl, Cl_2

```
Two-sample T for Cl vs Cl_2

       N    Mean   StDev  SE Mean
Cl     8  0.0575  0.0396    0.014
Cl_2  19  0.0563  0.0377   0.0087


Difference = mu (Cl) - mu (Cl_2)
Estimate for difference:  0.0012
95% CI for difference:  (-0.0347, 0.0370)
T-Test of difference = 0 (vs not =): T-Value = 0.07  P-Value = 0.944  DF = 12
```

Two-Sample T-Test and CI: Cl_1, Cl_2

```
Two-sample T for Cl_1 vs Cl_2

       N    Mean   StDev  SE Mean
Cl_1   6  0.0950  0.0929    0.038
Cl_2  19  0.0563  0.0377   0.0087


Difference = mu (Cl_1) - mu (Cl_2)
Estimate for difference:  0.0387
95% CI for difference:  (-0.0613, 0.1387)
T-Test of difference = 0 (vs not =): T-Value = 0.99  P-Value = 0.366  DF = 5
```

Two-Sample T-Test and CI: Ca, Ca_1

```
Two-sample T for Ca vs Ca_1

      N    Mean   StDev  SE Mean
Ca    8  0.1438  0.0632    0.022
Ca_1  6  0.1200  0.0587    0.024


Difference = mu (Ca) - mu (Ca_1)
Estimate for difference:  0.0238
95% CI for difference:  (-0.0484, 0.0959)
T-Test of difference = 0 (vs not =): T-Value = 0.73  P-Value = 0.484  DF = 11
```

Two-Sample T-Test and CI: Ca, Ca_2

```
Two-sample T for Ca vs Ca_2

       N    Mean   StDev  SE Mean
Ca     8  0.1438  0.0632    0.022
Ca_2  19   0.188   0.207    0.047


Difference = mu (Ca) - mu (Ca_2)
Estimate for difference:  -0.0447
95% CI for difference:  (-0.1531, 0.0637)
T-Test of difference = 0 (vs not =): T-Value = -0.85  P-Value = 0.403  DF = 23
```

Two-Sample T-Test and CI: Ca_1, Ca_2

```
Two-sample T for Ca_1 vs Ca_2

       N    Mean   StDev  SE Mean
Ca_1   6  0.1200  0.0587    0.024
Ca_2  19   0.188   0.207    0.047


Difference = mu (Ca_1) - mu (Ca_2)
Estimate for difference:  -0.0684
95% CI for difference:  (-0.1785, 0.0417)
T-Test of difference = 0 (vs not =): T-Value = -1.29  P-Value = 0.211  DF = 22
```

Two-Sample T-Test and CI: Fe, Fe_3

```
Two-sample T for Fe vs Fe_3

      N   Mean  StDev  SE Mean
Fe    8  0.226  0.112    0.040
Fe_3  6  0.468  0.607     0.25


Difference = mu (Fe) - mu (Fe_3)
Estimate for difference:  -0.242
95% CI for difference:  (-0.887, 0.403)
T-Test of difference = 0 (vs not =): T-Value = -0.96  P-Value = 0.379  DF = 5
```

Two-Sample T-Test and CI: Fe, Fe_1

```
Two-sample T for Fe vs Fe_1

       N   Mean  StDev  SE Mean
Fe     8  0.226  0.112    0.040
Fe_1  19  0.239  0.108    0.025


Difference = mu (Fe) - mu (Fe_1)
Estimate for difference:  -0.0132
95% CI for difference:  (-0.1155, 0.0890)
T-Test of difference = 0 (vs not =): T-Value = -0.28  P-Value = 0.783  DF = 12
```

Two-Sample T-Test and CI: Fe_3, Fe_1

```
Two-sample T for Fe_3 vs Fe_1

       N   Mean  StDev  SE Mean
Fe_3   6  0.468  0.607     0.25
Fe_1  19  0.239  0.108    0.025


Difference = mu (Fe_3) - mu (Fe_1)
Estimate for difference:  0.229
95% CI for difference:  (-0.411, 0.869)
T-Test of difference = 0 (vs not =): T-Value = 0.92  P-Value = 0.400  DF = 5
```

Two-Sample T-Test and CI: K, K_1

```
Two-sample T for K vs K_1

     N   Mean  StDev  SE Mean
K    8  0.144  0.189    0.067
K_1  6  0.135  0.221    0.090


Difference = mu (K) - mu (K_1)
Estimate for difference:  0.009
95% CI for difference:  (-0.245, 0.263)
T-Test of difference = 0 (vs not =): T-Value = 0.08  P-Value = 0.940  DF = 9
```

Two-Sample T-Test and CI: K, K_2

```
Two-sample T for K vs K_2

      N   Mean  StDev  SE Mean
K     8  0.144  0.189    0.067
K_2  19  0.100  0.153    0.035


Difference = mu (K) - mu (K_2)
Estimate for difference:  0.0437
95% CI for difference:  (-0.1222, 0.2097)
T-Test of difference = 0 (vs not =): T-Value = 0.58  P-Value = 0.573  DF = 11
```

Two-Sample T-Test and CI: K_1, K_2

```
Two-sample T for K_1 vs K_2

      N   Mean  StDev  SE Mean
K_1   6  0.135  0.221    0.090
K_2  19  0.100  0.153    0.035


Difference = mu (K_1) - mu (K_2)
Estimate for difference:  0.0350
95% CI for difference:  (-0.2021, 0.2721)
T-Test of difference = 0 (vs not =): T-Value = 0.36  P-Value = 0.730  DF = 6
```

Two-Sample T-Test and CI: Ti, Ti_1

```
Two-sample T for Ti vs Ti_1

      N    Mean   StDev  SE Mean
Ti    8  0.0175  0.0292    0.010
Ti_1  6  0.0200  0.0400    0.016


Difference = mu (Ti) - mu (Ti_1)
Estimate for difference:  -0.0025
95% CI for difference:  (-0.0470, 0.0420)
T-Test of difference = 0 (vs not =): T-Value = -0.13  P-Value = 0.900  DF = 8
```

Two-Sample T-Test and CI: Ti, Ti_2

```
Two-sample T for Ti vs Ti_2

       N    Mean   StDev  SE Mean
Ti     8  0.0175  0.0292    0.010
Ti_2  19  0.0126  0.0319   0.0073


Difference = mu (Ti) - mu (Ti_2)
Estimate for difference:  0.0049
95% CI for difference:  (-0.0223, 0.0320)
T-Test of difference = 0 (vs not =): T-Value = 0.38  P-Value = 0.706  DF = 14
```

Two-Sample T-Test and CI: Ti_1, Ti_2

```
Two-sample T for Ti_1 vs Ti_2

       N    Mean   StDev  SE Mean
Ti_1   6  0.0200  0.0400    0.016
Ti_2  19  0.0126  0.0319   0.0073


Difference = mu (Ti_1) - mu (Ti_2)
Estimate for difference:  0.0074
95% CI for difference:  (-0.0350, 0.0497)
T-Test of difference = 0 (vs not =): T-Value = 0.41  P-Value = 0.693  DF = 7
```

Two-Sample T-Test and CI: Mg, Mg_1

```
Two-sample T for Mg vs Mg_1

      N    Mean   StDev  SE Mean
Mg    8  0.0075  0.0104   0.0037
Mg_1  6   0.047   0.114    0.047


Difference = mu (Mg) - mu (Mg_1)
Estimate for difference:  -0.0392
95% CI for difference:  (-0.1595, 0.0812)
T-Test of difference = 0 (vs not =): T-Value = -0.84  P-Value = 0.441  DF = 5
```

Two-Sample T-Test and CI: Mg, Mg_2

```
Two-sample T for Mg vs Mg_2

       N    Mean   StDev  SE Mean
Mg     8  0.0075  0.0104   0.0037
Mg_2  19  0.0121  0.0270   0.0062


Difference = mu (Mg) - mu (Mg_2)
Estimate for difference:  -0.00461
95% CI for difference:  (-0.01945, 0.01024)
T-Test of difference = 0 (vs not =): T-Value = -0.64  P-Value = 0.528  DF = 24
```

Two-Sample T-Test and CI: Mg_1, Mg_2

```
Two-sample T for Mg_1 vs Mg_2

       N    Mean   StDev  SE Mean
Mg_1   6   0.047   0.114    0.047
Mg_2  19  0.0121  0.0270   0.0062


Difference = mu (Mg_1) - mu (Mg_2)
Estimate for difference:  0.0346
95% CI for difference:  (-0.0865, 0.1556)
T-Test of difference = 0 (vs not =): T-Value = 0.73  P-Value = 0.496  DF = 5
```

Two-Sample T-Test and CI: S, S_1

```
* ERROR * All values in column are identical.
```

Two-Sample T-Test and CI: S, S_2

```
Two-sample T for S vs S_2

      N    Mean   StDev  SE Mean
S     8  0.0063  0.0177   0.0063
S_2  19  0.0405  0.0518    0.012


Difference = mu (S) - mu (S_2)
Estimate for difference:  -0.0343
95% CI for difference:  (-0.0620, -0.0066)
T-Test of difference = 0 (vs not =): T-Value = -2.55  P-Value = 0.017  DF = 24
```

Two-Sample T-Test and CI: S_1, S_2

```
* ERROR * All values in column are identical.
```

Two-Sample T-Test and CI: Ni, Ni_1

```
* ERROR * All values in column are identical.
```

Two-Sample T-Test and CI: Ni, Ni_2

```
Two-sample T for Ni vs Ni_2

       N    Mean   StDev  SE Mean
Ni     8  0.0050  0.0141   0.0050
Ni_2  19  0.0037  0.0112   0.0026


Difference = mu (Ni) - mu (Ni_2)
Estimate for difference:  0.00132
95% CI for difference:  (-0.01120, 0.01383)
T-Test of difference = 0 (vs not =): T-Value = 0.23  P-Value = 0.820  DF = 10
```